PRICKLY PEAR CREEK MONTANA—

A STREAM CORRIDOR MANAGEMENT PLAN

APRIL 1984

streamworks

PRICKLY PEAR CREEK

A Stream Corridor Management Plan

Jefferson and Lewis and Clark Counties
Montana

prepared for the

Jefferson and Lewis and Clark
Conservation Districts

by

STREAMWORKS
614 Hollins
Helena, MT 59601

April, 1984

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (continued)

PRICKLY PEAR CREEK
A Stream Corridor Management Plan

EXECUTIVE SUMMARY

Beset by pollution from heavy metals, ammonia, and sediment, and completely dry in one stretch during most summers, Prickly Pear Creek cannot sustain a viable trout fishery for much of its length. The eroding banks that produce high concentrations of suspended sediment also threaten bridges, houses, and cropland.

If the creek is to be returned to a healthier, safer condition, its many problems, their causes, and their interrelationships must be understood. Previous studies of the creek identified major concerns. The current study collected the detailed data necessary to develop a management plan with the understanding needed to recommend site-specific corrective measures.

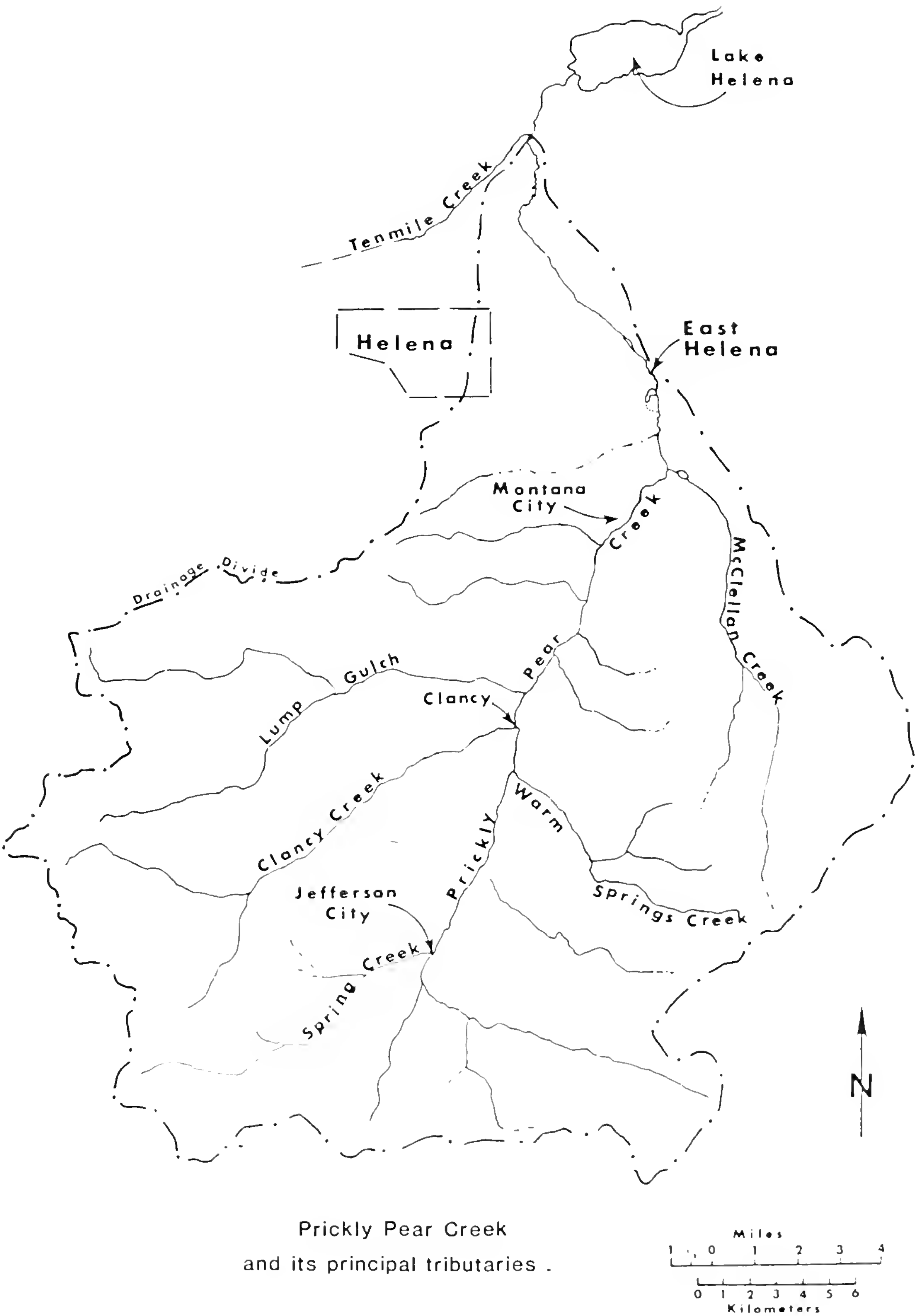
Streamworks, extending the past research with field observations, study of aerial photos, and other methods, developed a management plan that recognizes both the abilities and the limitations of the Conservation Districts in dealing with the many problems. More than 500 problem sites were identified, rated, and grouped into 18 channel reaches. The report contains descriptions of reclamation techniques recommended for each site and cost estimates for the work.

PROBLEMS AND POTENTIAL SOLUTIONS

Prickly Pear Creek begins its nearly 40-mile course in the Elkhorn Mountains, flowing to Lake Helena after joining Ten Mile Creek. A small stream, Prickly Pear has an average annual flow of 48 cubic feet per second (cfs).

A healthy stream is in a state of dynamic equilibrium. Erosion and sedimentation, neither excessive, are in balance. Water quality is good--for both people and fish. Vegetated, stable banks buffer against floods, hide fish, provide forage and shelter for livestock, offer habitat for game and non-game animals, and furnish recreation to society.

Although about one-half of Prickly Pear Creek is inhabited by trout year-round, productivity is below optimum levels. The middle section, from Clancy to East Helena, supports the most healthy trout populations; here, the fishery is about average for Montana streams. Other portions of the stream, however, support no trout at all. The absence of fish in many reaches is indicative of the poor health of the stream.



Prickly Pear Creek
and its principal tributaries .

Four major problems prevent Prickly Pear Creek from being healthy. In its reaches below East Helena, the creek is polluted by ammonia, and one three-mile stretch is nearly completely dewatered during the summer. Heavy metals and acid drainage from mining pollute its upper reaches below Jefferson City. Water quality in the entire stream suffers from high concentrations of suspended sediment.

Heavy Metals and Acid Mine Drainage.

Since the mid-1860s. hard rock mining has created high levels of heavy metals in Prickly Pear Creek. Highly toxic to fish even in minute concentrations, metals such as zinc, copper, and cadmium pollute the creek severely in the three miles below its confluence with Spring Creek. Between there and Lump Gulch Creek, the metals are diluted by tributaries, but still pose a hazard to trout and other aquatic life.

A study by the Montana Department of Fish, Wildlife, and Parks found that cutthroat trout placed below the Spring Creek confluence all died within 24 hours, while a group of control fish placed above the confluence all survived. Hatchery cutthroats may be less tolerant than the resident brook trout to toxic metals, but the results demonstrate the poor quality of this segment of the creek.

The Federal Office of Surface Mining funded preparation of a reclamation plan for the abandoned mines causing the pollution. The plan, published in 1983, suggested ways of preventing ground and surface water from coming into contact with waste dumps and mine workings and treating degraded water to remove the chemical and physical impurities. The Montana Department of State Lands, which had applied for the reclamation plan funding, and the Office of Surface Mining are considering the recommended reclamation measures and may join a private mining company in funding the actual work.

The cost of such a large-scale project would be far more than the Conservation Districts could afford. However, the Districts should urge the state and federal agencies to pursue reclamation, and assist by providing technical review of proposed plans and specifications. Increasing flows in Spring Creek by storing water during spring runoff could enhance reclamation by increasing the stream's diluting capacity. Strong controls on any future mining activities in the Prickly Pear drainage are essential.

Ammonia.

The City of Helena's wastewater treatment plant discharges effluent containing ammonia into Prickly Pear via a ditch about 4.5 miles upstream from Lake Helena. Although the plant provides waste treatment comparable to that of

other large Montana cities, its discharge is received by a much smaller stream than the others. During peak irrigation periods, this wastewater constitutes about one-third of the flow in lower reaches of the creek. This effluent typically contains ammonia concentrations seven times greater than the level toxic to fish. In the stream, the ammonia presents a potential barrier to spring runs of rainbow trout spawning from Hauser Reservoir, and to fall runs of brown trout.

One possible solution would be to reroute several irrigation drain ditches, to allow wastewater to enter directly into Lake Helena, with its greater dilution capability. Other potential remedies include in-plant treatment--converting ammonia to less-toxic compounds before releasing the wastewater--or land treatment/rapid infiltration, in which the discharge is percolated through a soil layer before discharge into the stream. While either type of treatment and their variations are technically feasible, the procedures would be costly.

As was the case with heavy metal pollution, the Conservation Districts can do little on their own to clean up the problem. They should, however, urge the City of Helena to investigate methods available to lower the concentrations of ammonia in Prickly Pear Creek, especially ammonia reduction through pH control with break-point chlorination or rapid (land) infiltration.

Dewatering.

Below East Helena, Prickly Pear Creek water is in great demand by agricultural users, and flows are insufficient to fulfill existing water rights. For several miles beginning about 1.5 miles north of East Helena, the creek is completely dry during normal summers, preventing the establishment of any resident trout fishery or riparian vegetation. Prickly Pear is gradually recharged by irrigation returns, springs, ground water infiltration, and wastewater from the treatment plant, but dewatering affects aquatic habitat, riparian vegetation, and channel and bank stability.

Possible solutions include: substituting ground-water-fed sprinkler irrigation for surface water diversion; purchasing water from the Helena Valley Canal; and storing spring runoff in reservoirs, abandoned gravel pits, or aquifers for release during low flow periods. All of these options have legal, technical, or financial drawbacks, but the most feasible seems to be installing ground-water-fed sprinkler systems to allow a portion of the presently-diverted water to remain in the creek.

Sediment.

Excessive levels of suspended sediment--very small particles such as clay and silt that are carried in suspension by streamflow--can damage aquatic insects, incubating trout eggs, and the gill structures of adult fish. Sediment deposited on the channel bottom can suffocate trout eggs and bottom-dwelling organisms.

The high concentrations of suspended sediment in Prickly Pear come mostly from bank erosion along the mainstem and tributaries. Abandoned mine dumps, eroding channel banks, breached settling ponds, and periodic flushing of sediment from behind the ASARCO dam in East Helena contribute to the problem. In many places the eroding banks that contribute to sedimentation also threaten bridges, houses, other structures, and cropland.

The floods of 1975 and 1981 focused much attention of the erosion problems of Prickly Pear Creek. Many already-eroding banks were worsened by these floods. However, the overall effect on the stream's channel was not significant.

In some reaches, Prickly Pear has banks actively eroding for up to 50 or 60 per cent of their total length. This high rate is caused in part by the sandy, easily-erodible bank materials common in the Helena Valley. Heavy grazing at several locations in the drainage contributes to erosion by removing riparian vegetation and trampling banks. Railroad and highway construction in the stream corridor have shortened and straightened sections of the creek, increasing its erosive power.

Banks can be stabilized, and sediment levels reduced, by using structural measures such as riprap to hold banks in place, or by using dikes or jetties to deflect flows away from banks. Reshaping banks, strengthening them with brush mats, or revegetating shorelines can serve the same purpose. These measures could be used in combination to inhibit bank erosion, encourage sediment deposition near banks, and allow replanted vegetation to grow successfully. The establishment of streamside vegetation is a crucial component of erosion control, adding to the longevity, effectiveness, and aesthetics of any structural measures. A systematic fencing and grazing management program for heavily grazed streambanks would allow many eroding banks to stabilize and recover.

Control of bank erosion and sedimentation would be complemented by measures to enhance fish and aquatic habitat. For example, overhanging cover along banks could be established by planting shrubs and other riparian vegetation. Midstream flow deflectors could create the pool-riffle contrasts favored by trout. Allowing the stream to return to a more natural, meandering course in its straightened segments would increase the amount of habitat.

RECOMMENDATIONS AND WORK PLAN ALTERNATIVES

The Conservation Districts should support and assist all efforts to correct the water quality and quantity problems in Prickly Pear Creek, but the dewatering, ammonia, and heavy metal impacts require a much greater financial commitment than will likely be available. Other agencies must spearhead these efforts.

Controlling erosion and sedimentation and improving instream aquatic habitat are well within the Districts' grasp. In reaches currently inhabited by trout, lowering of sediment levels will improve water quality, creating very favorable conditions. The best strategy in carrying out erosion control measures, therefore, is to concentrate them where they will do the most good. The stream reaches between Clancy and East Helena provide the best aquatic habitat, and so are prime candidates for the Districts' attention. Along Clancy Creek, sediment control through fencing and grazing management deserves attention.

However, these measures will not be very effective in the stream reaches subject to dewatering, ammonia, or heavy metals. The presence of these conditions alone severely limits fish populations, so lowering sediment levels would not result in greater numbers of fish using the areas. The areas below East Helena, where dewatering and ammonia are limiting factors, should receive a lower priority for much work, as should the upper reaches from Spring Creek to Clancy, where heavy metal pollution is concentrated. In these stream sections, it makes sense to protect structures from collapsing because of bank erosion, and to correct the most extreme erosion problem sites. More-extensive work would not be effective.

Based on this premise, and recognizing potential funding limitations, **Streamworks** developed three work plan alternatives. The primary components of each are channel improvements to protect structures and reduce sediment pollution, revegetation, fencing to reduce grazing pressure on streambanks, reduction of sediment pollution at specific high-priority problem sites, and fish habitat improvement demonstration projects. The differences among the alternatives are simply in how many problem areas can be treated for the money.

Alternative A, at a cost of $639,500, would treat all of the most important problem sites drainage-wide, resulting in the greatest level of improvement. Alternative B, costing $479,900, would treat from 50 to 80 per cent of the sites (depending on the type of reclamation planned and the location of treatment) addressed by the first option. Alternative C, at $279,300, would treat between 20 and 60 percent of the sites done under Alternative A. Each alternative includes a 25 per cent allowance for final engineer-

ing design, cost estimation, and contingencies.

Alternative C represents a good starting point that would show the effectiveness of site treatment, perhaps spurring interest among the landowners and public to see these improvements made throughout the drainage.

Streamworks identified a wide variety of potential funding sources for the recommended work. The Department of Natural Resources and Conservation, the Department of Fish, Wildlife and Parks, the Department of State Lands, ASARCO, the National Endowment for Soil and Water Conservation, the Department of Health and Environmental Sciences, the Montana Department of Highways, and Burlington Northern are all possibilities for involvement in various reclamation activities.

Obtaining funding, however, will be a necessary but not sufficient part of the cleanup effort. The support of landowners along the creek is essential, requiring continued communication among landowners and the Districts. Landowners contacted by Streamworks were generally receptive to proposed channel modifications.

Carrying out any of the three alternatives will also require administrative participation by the Montana Department of Health and Environmental Sciences, the Montana Department of Natural Resources and Conservation, the Montana Department of Fish, Wildlife and Parks, the Conservation Districts, and the Soil Conservation Service. It may be necessary to hire a short-term project coordinator to organize this participation, as well as deal with landowners, do contracting, supervise construction, and conduct fund-raising activities.

Another important component of stream rehabilitation should be the collecting of detailed baseline information on fisheries and water quality. This information will provide a basis from which to judge the effectiveness of cleanup measures. For future work to be designed and carried out, it is necessary to know why any stream modifications were effective, and how well they worked--not just that an improvement was made.

CHAPTER I.

INTRODUCTION

Prickly Pear Creek and its watershed have provided a wide variety of benefits over the past 120 years: mineral wealth; a corridor for utilities, transportation, and wastewater disposal; grazing, water, cropland, and timber resources; and homesites. This multiple use of the stream, however, has taken its toll, and today the creek is polluted for much of its length by heavy metals, ammonia, and sediment. The trout fishery--one of the most visible indicators of a stream's biological health--is extremely limited, suffering not only from poor water quality but from severe dewatering in its lower stretches for much of the summer. Bank erosion and channel instability threaten roads, houses, cropland, and other floodplain uses.

Landowners and the recreating public alike want Prickly Pear returned to a safe, healthy condition. With careful planning and the mutual support of all concerned, this outcome is indeed possible. Parts of the stream are surprisingly stable, with banks revegetating rapidly after being damaged by channelization during the 1970's and by washout during the 1981 flood.

As an initial step in the reclamation of Prickly Pear Creek, the Montana Department of Health and Environmental Sciences in 1980 conducted an analysis of water quality problems, including a streambank inventory, in the entire drainage (Montana DHES 1981). Designed to identify the overall scope of watershed problems, this study did not attempt to collect the detailed information necessary to develop site-specific rehabilitation measures. Another study was needed, in part to assess the effects on the steam channel of the flood of May 1981.

This report provides the level of information needed to develop a sound stream corridor management program. In a watershed as disturbed as Prickly Pear's, an understanding of the individual problems, their causes, and their interrelationships was essential to develop remedial measures. Problems in one stream segment often affect other reaches, whether they are located upstream or downstream. Analysis of the stream's history, hydrology and channel dynamics, aquatic life, and riparian vegetation allowed us to recommend a comprehensive management plan and assign priorities to its various components.

Several methods were employed in Streamworks' analysis. In addition to the Montana DHES (1981) report, we used the results of a riparian vegetation study (Husby and Moore 1982) and public comment obtained at a meeting in the Helena Valley in January, 1984. Field observations of streambank conditions and channel characteristics conducted during the summer and fall, 1983, were supplemented by study of historic aerial photographs and maps, and analysis of a longitudinal channel profile for much of the stream. As part of this work, more than 500 problem sites were identified and grouped into 18 channel reaches on Prickly Pear Creek. These reaches, shown on figure II-1, are referred to throughout the text.

Chapter II describes the existing environment and the channel stability, water quality, and aquatic habitat problems which beset Prickly Pear Creek. Chapter III contains a general analysis of methods for correcting these problems and their associated costs. Chapter IV lists recommendations for stream corridor management and site priorities for rehabilitation, and Chapter V outlines possible funding sources to assist the management program. The appendices provide greater detail on: bank and channel stabilization; revegetation methods; recommendations for specific problem sites; channel rehabilitation costs; instream flow requirements and rewatering Prickly Pear Creek; U.S. Geological Survey streamflow measurements; and Streamworks personnel who prepared this report.

Readers concerned with the location of specific channel problem sites should consult Appendix C and large-scale aerial photos and maps on file with the Lewis and Clark County Conservation District, at the Federal Building in Helena.

CHAPTER II.

EXISTING ENVIRONMENT AND PROBLEMS

PHYSICAL SETTING and HISTORY.

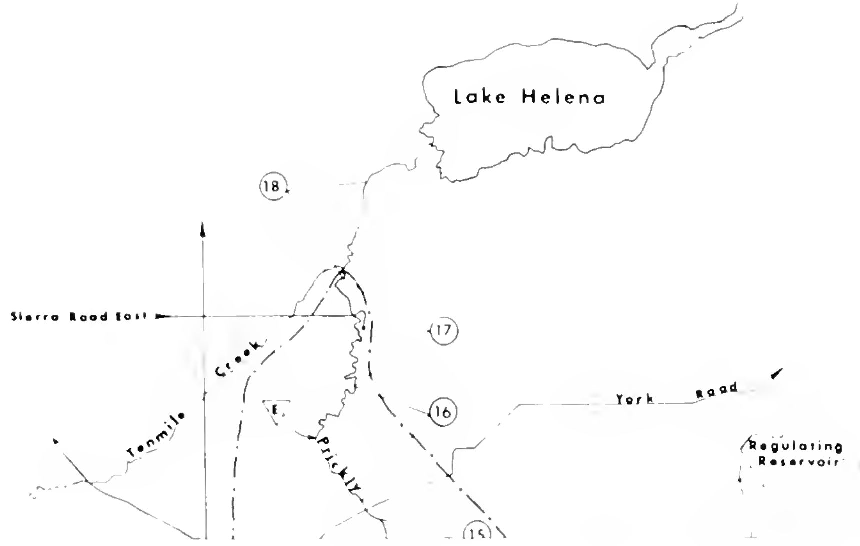
Prickly Pear Creek, a small, mostly gravel-floored stream originating in the forested Elkhorn Mountains, flows north to Lake Helena in the semiarid Helena Valley (figure II-1). Throughout much of the creek's almost forty-mile length, the channel bed and banks consist of sand, gravel, and cobbles. Much of this material is sufficiently fine-grained to erode and be transported by annual floods, except where the banks are riprapped with large boulders and crushed rock.

Elevation in the drainage ranges from 9,381 feet on Elkhorn Peak to 3,550 feet at Lake Helena. The stream drops approximately 3,600 feet in its forty-mile course. In the mountainous drainage south of East Helena, the stream valley is narrow, rarely exceeding 2,000 feet in width and often having a flood plain 100 to 200 feet wide. Approximately one mile upstream from East Helena, the stream leaves the steeper mountain valley and flows onto a well-developed alluvial fan. The fan, a deposit of stream sediment that has formed during the past million years, slopes more gently than Prickly Pear's valley further upstream. Because of this change in slope, the stream has deposited much of its sediment on the fan.

Streams on alluvial fans often have broad, shallow, branching channels that are easily overtopped by floods and subject to abrupt lateral shifts. The 1981 flood showed Prickly Pear Creek to be this type of stream along several reaches.

An aerial view of the stream and alluvial fan north of East Helena shows many dry channels, forming a network (braided) pattern. Most of these channels carried water during the 1981 flood, but are only active during infrequent floods. The main channel on the fan meanders intricately, occupying a much broader flood plain (typically 500 to 1,000 feet wide) than is present in the mountains.

During the late 1800s and early 1900s, a wealth of silver, gold, lead, and copper was extracted by hard rock mining in Prickly Pear's headwater tributaries. Placer gold was dredged from the creek's floodplain deposits over nearly


Lake Helena
18
Sierra Road East
17
Creek
16
York Road
E
Prickly
Tenmile
Regulating Reservoir
15

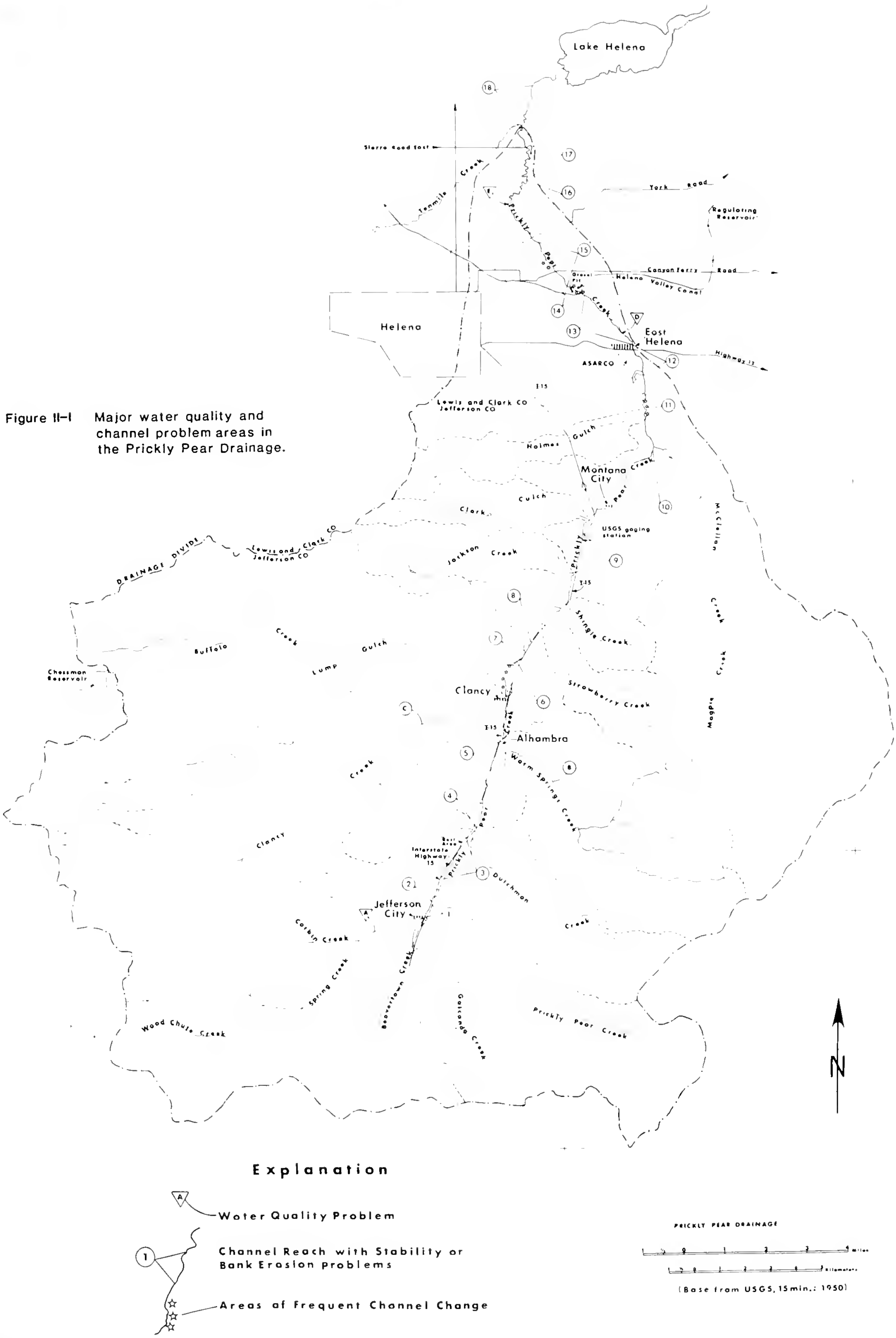


Figure II-I Major water quality and channel problem areas in the Prickly Pear Drainage.

its entire length between East Helena and Jefferson City, and along many tributaries. Prickly Pear's precious metal resources are not yet exhausted; mining companies have recently unveiled preliminary plans to mine gold, high in the drainage, along Spring Creek west of Jefferson City.

Prickly Pear Creek also continues to provide valuable water for industrial, municipal, and agricultural users. The low relief of the stream's floodplain and nearby terraces, coupled with fertile soils, provides valuable bottom lands for cropping and grazing, especially north of East Helena.

In the mountainous portion of the drainage, particularly between Jefferson City and Montana City, Prickly Pear's floodplain has served as a natural corridor for the construction of highways and a railroad, resulting in modification or complete relocation of much of the stream channel. The stream has been altered for approximately 12 miles (24 bank-miles), about 36 per cent of its mainstem length. In spite of extensive reliance on riprapping (7 bank-miles so far), bank erosion continues unabated along many reaches. Along most of the channelized segments, large riprap (two- to five-foot diameter) defines the banks of the stream and controls its lateral position. Elsewhere, the stream is subject to the natural processes of bank erosion and lateral migration of the channel across its flood plain. In many places, healthy bank vegetation greatly slows erosion and channel wandering.

Husby and Moore (1982) inventoried and mapped the vegetation adjacent to Prickly Pear Creek to document adverse impacts to the watershed. This vegetation is composed of native plant communities, range and pasture, and alfalfa/hay fields. The most common riparian forest community is dominated by black cottonwood with a shrub understory of rose, currant, snowberry and willow. The herbaceous component of this community is dominated by introduced grasses such as Kentucky bluegrass, smooth brome, meadow foxtail, redtop, and quackgrass.

The native shrub communities along the stream are variable in species composition; the dominants are willow, alder, rose, snowberry, chokecherry, buffaloberry and serviceberry. Often, particularly on gravel bars, willow forms dense stands as an early successional stage in plant community development. Where heavy grazing has occurred, development of shrub communities has been impaired.

Marshland, dominated by cattails and other aquatic plant species, occupies sites that are wet throughout the growing season. Old oxbows of the stream and springs or seeps support the marshy areas.

its entire length between East Helena and Jefferson City, and along many tributaries. Prickly Pear's precious metal resources are not yet exhausted; mining companies have recently unveiled preliminary plans to mine gold, high in the drainage, along Spring Creek west of Jefferson City.

Prickly Pear Creek also continues to provide valuable water for industrial, municipal, and agricultural users. The low relief of the stream's floodplain and nearby terraces, coupled with fertile soils, provides valuable bottom lands for cropping and grazing, especially north of East Helena.

In the mountainous portion of the drainage, particularly between Jefferson City and Montana City, Prickly Pear's floodplain has served as a natural corridor for the construction of highways and a railroad, resulting in modification or complete relocation of much of the stream channel. The stream has been altered for approximately 12 miles (24 bank-miles), about 36 per cent of its mainstem length. In spite of extensive reliance on riprapping (7 bank-miles so far), bank erosion continues unabated along many reaches. Along most of the channelized segments, large riprap (two- to five-foot diameter) defines the banks of the stream and controls its lateral position. Elsewhere, the stream is subject to the natural processes of bank erosion and lateral migration of the channel across its flood plain. In many places, healthy bank vegetation greatly slows erosion and channel wandering.

Husby and Moore (1982) inventoried and mapped the vegetation adjacent to Prickly Pear Creek to document adverse impacts to the watershed. This vegetation is composed of native plant communities, range and pasture, and alfalfa/hay fields. The most common riparian forest community is dominated by black cottonwood with a shrub understory of rose, currant, snowberry and willow. The herbaceous component of this community is dominated by introduced grasses such as Kentucky bluegrass, smooth brome, meadow foxtail, redtop, and quackgrass.

The native shrub communities along the stream are variable in species composition; the dominants are willow, alder, rose, snowberry, chokecherry, buffaloberry and serviceberry. Often, particularly on gravel bars, willow forms dense stands as an early successional stage in plant community development. Where heavy grazing has occurred, development of shrub communities has been impaired.

Marshland, dominated by cattails and other aquatic plant species, occupies sites that are wet throughout the growing season. Old oxbows of the stream and springs or seeps support the marshy areas.

The rangeland and pasture adjacent to Prickly Pear Creek are dominated primarily by introduced grasses. The forbs which occur are often invader species such as burdock, lambsquarters, tumble mustard, berteroa, and leafy spurge.

Only a few miles from downtown Helena, Prickly Pear Creek provides a unique recreational opportunity for local residents. Trout fishing, bird watching, berry picking, and picnicking are enjoyed by increasing numbers of users along scattered parcels of public land as well as highway and railroad rights-of-way and private lands.

These recreational pursuits are presently concentrated in the segment of stream between East Helena and Clancy, where suitable water quality, riparian habitat, and year-round streamflows provide a viable fishery. Other mountain trout streams with similar recreational benefits, e.g. Little Prickly Pear Creek, Beaver Creek, the upper Little Blackfoot, or the Boulder River, require nearly an hour's travel from Helena.

Local groups such as the Prickly Pear Sportsmen's Association, Last Chance Audubon Society, the Helena Outdoor Club, and the Prickly Pear Task Force have long recognized the existing and potential value of this "backyard trout stream." Their interest and concern helped to demonstrate the need for a Prickly Pear Creek management plan.

The recreational use of Prickly Pear Creek is limited by water pollution, unsuitable fish habitat, dewatering, and the lack of designated sites for public access. However, the stream has the potential to become healthy, capable of supporting a fishery for most of its length. Few other state capitals have trout streams so close to their city limits. One of the most worthwhile benefits of the reclamation of Prickly Pear Creek will be the enhancement and expansion of recreational opportunities along the stream.

HYDROLOGY and CHANNEL STABILITY.

Hydrology.

The Prickly Pear drainage contains about 270 square miles above the confluence with Ten Mile Creek just above Lake Helena. Annual precipitation in the watershed ranges from a low of 10 inches in the Helena Valley to a high of 30 inches in the Elkhorn Mountains, averaging about 19 inches over the entire basin. The relatively small area and low annual precipitation result in a small average annual streamflow (or surface runoff)--about 35,000 acre-feet per year from 192 square miles of the upper drainage. About 60 per cent of this annual flow leaves the watershed between

April and July. Excessive demand placed on the limited water resource leads to chronic dewatering below East Helena.

The U.S. Geological Survey has made long-term measurements of streamflow on Prickly Pear Creek, at a point about four miles northeast of Clancy (figure II-1). Measurements at this station (06061500) represent the upper 70 per cent of the drainage and include the flow produced by all major tributaries except McClellan Creek. Extremes and averages for this station are summarized in table II-1 and figure II-2. A more complete summary of streamflow characteristics for the station is given in Appendix J.

TABLE II-1

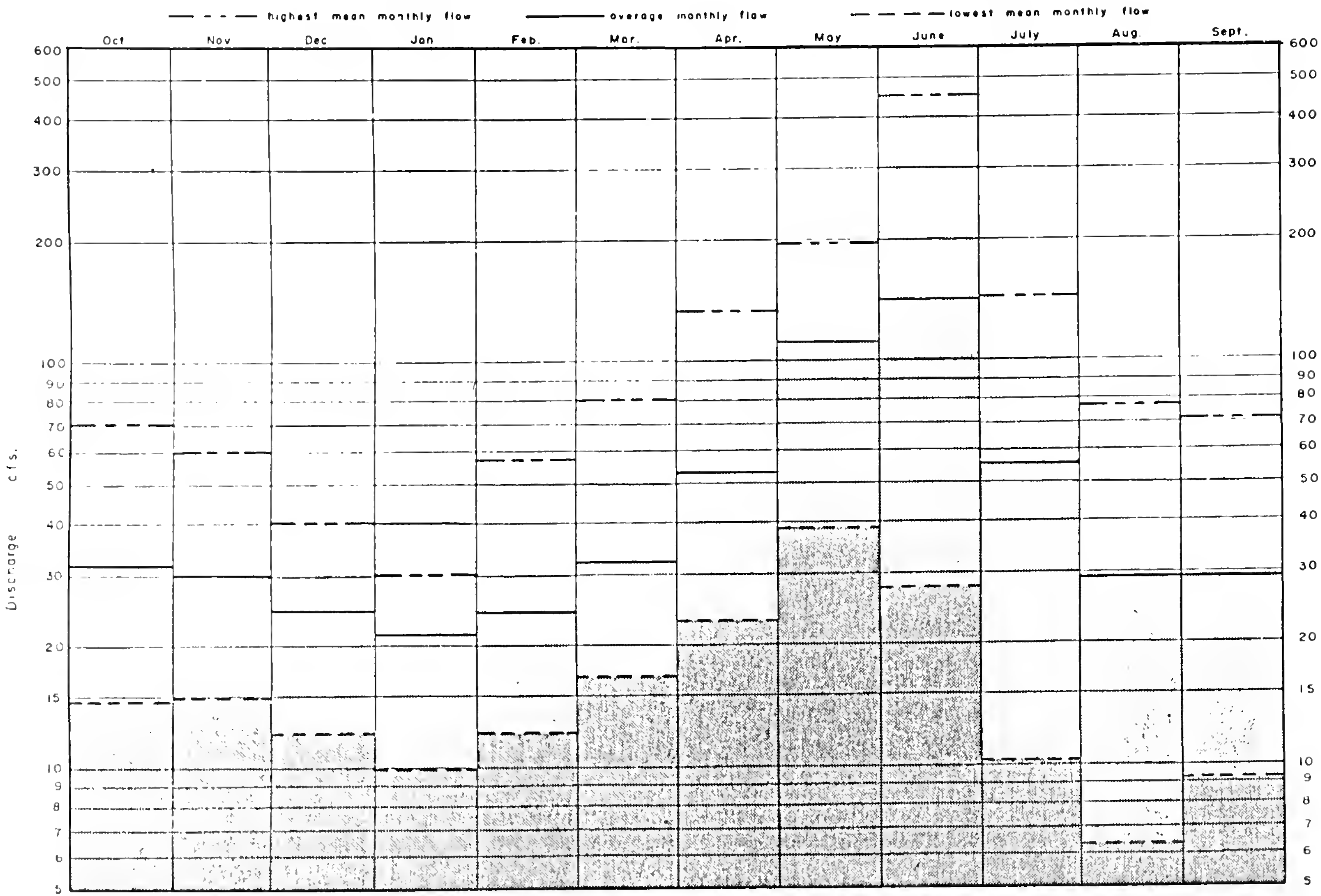
Summary of Extreme and Average Flows
Prickly Pear Creek near Clancy

Period of record	Intermittent from 1908 to present
Drainage area	192 square miles
Average annual flow	48 cubic feet per second (cfs)
Average winter monthly flow (Nov.-Mar.)	26 cfs
Average summer monthly flow (June-Sept.)	70 cfs
Minimum instantaneous low flow	0.5 cfs (January 26, 1958)
Maximum instantaneous peak flow	2,300 cfs (May 22, 1981)

Source: Compiled from U.S.G.S. 1981, 1982

Natural stream systems experience wide ranges of flows on an annual basis, as well as over the long term. Most stream channels adjust in width, depth, and slope to accommodate relatively frequent flood flows (Dunne and Leopold

Figure II-2 Stream Hydrograph for Prickly Creek near Clancy (1909-1969).



(Source: DNRC, 1974)

1978, Andrews 1980). For example, in many gravel-bed streams the bankfull discharge (the flow that fills the channel to its bank top) has an average recurrence interval of about two years (Bray 1982). In most cases bankfull discharge is the dominant, channel-forming flow responsible for shaping and maintaining the stream channel. More frequent, lower velocity streamflows generally have insufficient energy to transport the sediment forming the channel boundary (Wolman and Miller 1960).

A very large flood (for example, a 50-, 100-, or 500-year flood) has the potential for significant channel modification. But these very infrequent floods allow ample time for the stream system to reestablish the pre-flood channel in response to the dominant discharge. Experience shows that stream recovery from major floods usually occurs in five to ten years.

In the past nine years, the Prickly Pear drainage has experienced two major floods with recurrence intervals greater than 100 years (Morrison-Maierle, Inc. 1983). On June 19, 1975, flow near Clancy peaked at 1,200 cubic feet per second (cfs). On May 22, 1981, discharge at the same point reached 2,300 cfs. While these floods caused extensive property damage, especially to urban areas, they did not have a catastrophic impact on the stream channel.

The 1981 flood caused much damage to roads and property, particularly in East Helena (Parrett et al. 1982). Aerial photos taken at the peak of the flood showed that in many places the flood occupied the entire floodplain. To assess the damage, we updated the two previous stream inventories (Montana DHES 1981, Husby and Moore 1982). Before-and-after comparison of the channel and banks showed much of the stream channel was relatively unaffected. Very few new bank erosion problems were created, but banks which were eroding prior to the flood often increased in length by five to twenty per cent.

As a result of the 1981 flood, only about six per cent (two miles) of the total channel length of the Prickly Pear mainstem experienced pronounced changes in channel pattern. Consequently, there was little need for extensive channel reconstruction after the flood. Major channel modifications such as abandonment of the existing channel, cutting of new channels, and the creation of braided channels, were restricted primarily to several tributary streams (Spring, Clancy, and Warm Springs creeks), and to channel reaches 6 (in the vicinity of the Marks-Miller post and pole plant), 11 (on Kleffner's property just above ASARCO), 12 (near ASARCO), 13 (just below East Helena), and 14 (near Helena Sand and Gravel on the Burnham property). (Channel reaches are identified on figure II-1.) In general, these reaches were straightened by the flood.

Channel Dimensions, Slope, and Sediment Load.

Prickly Pear Creek transports several sizes of sediment, ranging from tiny, almost microscopic particles of clay to large pebbles, cobbles, and boulders. Very small particles, such as clay and silt, are transported in suspension by streamflow and comprise the "wash load" of the stream. Material this size is generally flushed through the stream to Lake Helena.

Coarse sand, gravel, and cobbles make up the channel bed at low flow and constitute the bed-material transported by the stream during floods. The bed-material load may be further divided into material transported in suspension (suspended bed-material) and sediment transported by rolling, sliding, and bouncing along the stream bed (bed load). A summary of two commonly used classifications of stream sediment loads is given in figure II-3. In later sections of this report we refer to wash load sediment and suspended bed-material collectively as fine sediment, and to bed load as coarse sediment.

In general, the wash load and suspended sediment are transported by a wide range of flows, while the larger-sized bed-material is moved only by flows near or above bankfull (Andrews, in press). Commonly, 90 to 95 per cent of bed-material transport in streams occurs over a five to fifteen day period of annual high flow.

Suspended sediment causes turbid water and, if excessive or unseasonal, may create water quality problems. Bed-material sediment is important because it largely forms the channel bed and banks. If too little or too much is supplied to the stream channel, stability problems may arise. Both types of sediment are derived from surface erosion of the watershed and subsequent bank erosion of materials stored in the floodplain.

In the Prickly Pear drainage, the suspended bed-material load is mainly sand which is transported in suspension by high flows, and by rolling, sliding, and bouncing at lower flows. Above East Helena, it is usually present downstream from tributaries (such as Spring Creek or Clancy Creek) or at and just downstream from large eroding channel banks. At some locations it forms waves of sand as high as one foot, blanketing the channel bottom. This material significantly reduces aquatic productivity and trout spawning success. Below East Helena and especially below the confluence with Ten Mile Creek, the sandy material is more prevalent.

The strongest determinants of the systematic, broad-scale, downstream changes in channel and sediment characteristics are the relief (difference in elevation) of the

FIGURE II-3

Commonly Used Classifications of Stream Sediment Loads.

Based on mode of transport.		Based on availability of material in stream bed.
Suspended sediment load (fine sediment transported in suspension)		Wash load (sediment finer than 0.0625 mm--usually not found in appreciable quantities on the streambed.
+	=	+
Bed load (coarse sediment transported in total or partial contact with the streambed)		Bed-material load (the portion of total sediment discharge which is comprised of grain-sizes found in the stream bed--may be divided into suspended bed-material and bedload fractions, depending on the mode of transport)

Source: After Thomas 1977, Andrews 1981.

drainage area and the amounts of water and sediment supplied to the channel. Soils, geology, vegetation, and land use also may influence the physical condition of the stream system.

Prickly Pear Creek undergoes several changes as drainage area increases from its headwaters to its mouth at Lake Helena: a progressive widening and deepening of the stream channel; a downstream decrease in the size of coarse-grained sediment in the channel bed; and a progressive reduction in the slope of the channel (table II-2).

These three changes are interrelated. The particle size of bed sediment decreases downstream, a result of rock weathering and abrasion. At the same time, streamflow

(discharge) increases as new tributaries enter the main channel. The net effect is that as discharge increases and particle size decreases, a progressively lower river slope is required to move the water and sediment supplied to the channel (Gilbert 1914, Leopold et al. 1964).

TABLE II-2

Typical Channel Dimensions and Sediment Size along Prickly Pear Creek*

Upstream ← → Downstream

Location	Just below Jefferson City	Just above Montana City	Burnham's (gravel pit area)	Below Sierra Road
Drainage area, sq. mi.	53	192	255	268
Width, ft.	10-25	25-45	40-110	50-125
Depth, ft.	1.5-2.0	2.0-2.5	2.0-3.0	2.5-3.5
Channel gradient	0.05-0.009	0.01-0.007	0.009-0.006	0.005-0.003
Median diameter of bed sediment, ft.	0.16-0.26	0.07-0.20	0.07-0.10	0.02-0.07

* Width refers to width at bankfull flow, roughly a two- to five-year flood. Depth refers to mean depth at bankfull flow. Channel gradient is the average range based on channel surveys of bed slope (over short distances slopes may vary outside these ranges). Median diameter of bed sediment is the size for which 50 per cent of surface bed material is smaller and 50 per cent is larger, based on surface pebble count and visual observations.

Channel Processes and Equilibrium.

The stability and dimensions of a channel are strongly influenced by the supply of water and sediment to the channel from the upstream watershed. A stream's response to a markedly altered water-sediment supply typically includes: altered rates of lateral channel migration; changes in channel width, sediment size, channel bed elevation, pool-riffle spacing, and slope; and a tendency for over-bank flow to become more or less frequent (Leopold *et al*. 1964, Schumm 1969, 1977, Dunne and Leopold 1978, Shen 1979).

In many streams not appreciably affected by human activities, a channel--with relatively stable bed, banks, and islands--develops in equilibrium with the amount of water and sediment supplied. This channel carries moderate sediment loads and experiences gradual downcutting and slow lateral migration as water and sediment move through the stream system.

Channel equilibrium is neither perfect nor static; it is a dynamic condition. However, over the short-term in a given channel reach, the channel form and the rates of erosion and deposition on the banks and bed fluctuate closely about average values.

Departures from the equilibrium condition have two extremes--active downcutting (degradation) and rapid accumulation of sediment (aggradation). While other factors may also be important, downcutting typically reflects a channel which is adjusting to several conditions: a deficit in bed-material sediment supplied by the watershed; an increase in streamflow available to transport sediment; or an increase in channel slope. Slope increase is usually caused by cutoff of natural meanders or artificial channelization.

Aggradation normally occurs in response to increases in bed-material supply or to decreases in the amount of streamflow available to transport sediment.

Variations in the slope and width of the valley may also cause a channel to aggrade or degrade. For example, in many small headwater tributaries the channel slopes are steep and sediment supply is small; downcutting occurs. Conversely, as the channel leaves the steeper mountain valley, it encounters a markedly decreased gradient, resulting in reduced sediment transport capacity and deposition of an alluvial fan.

Some stream systems never reach equilibrium, or attain it only for select portions of the channel network. Geologic uplift, extreme floods, or a change in climate may cause natural alteration of a channel (Schumm 1977).

Through a variety of watershed activities, man may also affect the ability of a stream to achieve equilibrium. For example, land use may greatly change the distribution, timing, or amount of runoff and sediment supplied to the channel system. If this happens, the downstream channel network will adjust its dimensions to accommodate the new combination of water and sediment runoff (Dunne and Leopold 1978).

Evaluation of Channel Equilibrium.

As erosion occurs along the concave bank of a meander bend, it is balanced by a nearly equal amount of deposition on the point bar located on the opposite convex bank. The channel gradually migrates laterally across the floodplain, reworking older floodplain deposits as it moves. As much as forty per cent of the channel bank within an equilibrium channel reach may be actively eroding at a modest rate. Whether or not natural erosion is a problem depends on its proximity to civil works, its impact on desired land use, and its overall effect on stream sediment loads and aquatic life. Stream life (fish, insects, and plants) flourish in channels with normal, natural amounts of bank erosion.

Stream channels which depart widely from equilibrium generally provide fewer benefits to landowners and the public. In addition, extreme channel stability problems may be very difficult and costly to correct. An important goal of stream corridor management is to maintain and enhance stream channel equilibrium.

Whether or not a channel segment is in equilibrium can be recognized using several criteria. First, the vertical position (elevation) of the channel bed at a particular location or over a short reach should not vary greatly over the short term (roughly five to fifty years). Second, the horizontal or lateral movement of the channel should proceed at a relatively uniform rate with the overall pattern (shape of the channel as viewed from the air) preserved through time. Last, the longitudinal (down-valley) profile of the stream bed should be relatively smooth; a gentle curve should connect steep sections in the headwaters with lower-gradient sections in the valley (Leopold *et al*. 1964).

The entire channel of Prickly Pear Creek was evaluated on each of these criteria. The methods used included:

field observations of the existing channel shape, dimensions, sediment characteristics, and physical streambank condition;

inspection of historic aerial photographs and maps to estimate the frequency of major channel pattern changes and the effects of the 1981 flood; and

analysis of a longitudinal channel profile of Prickly Pear from near Jefferson City to its juncture with Lake Helena.

Synthesis of these data provided a comprehensive, drainage-wide framework for identifying the causes of bank erosion and channel stability problems. With this understanding, it was possible to identify critical problem areas and recommend remedial measures. Over 500 individual problem sites were evaluated and grouped into 18 channel reaches for further consideration. For a general description of these problem areas and potential solutions see Chapter III; specific problem sites are tabulated in Appendix C, table C-1.

In contrast to a stream that has reached an equilibrium between sediment erosion and deposition, some sections of Prickly Pear have active erosion along as much as 60 per cent of the total bank length. Erosion on Prickly Pear occurs along relatively straight channel reaches, as well as along the outsides of channel bends, where erosion is present even in equilibrium streams.

Excessive bank erosion, the most prevalent channel problem along much of Prickly Pear and several of its tributaries, is particularly noticeable in channel reaches 6, 11, 14, 15 (marked by stars on figure II-1); these reaches exhibit lateral instability and a lack of channel equilibrium. In combination, excessive bank erosion and channel instability contribute to greater sediment loads in Prickly Pear throughout its length, creating excessive seasonal turbidity and a reduction in the quality of aquatic habitat.

Bank Erosion.

As part of our review and up-date of the 1981 physical streambank inventory (Montana DHES 1981), the cause of bank erosion at individual sites was noted. Distinctions were made between: bank erosion resulting from direct entrainment and undercutting of banks; and mechanical bank failure caused by high soil moisture, sharp bends, and poor channel alignment. Other factors which can contribute to erosion were noted, among them bank material type, extent of vegetation cover, and land use.

The Prickly Pear Creek mainstem contains many individual erosion sites, each with a relatively rapid rate of bank erosion. At some locations, the banks are long (more than 1,000 feet) and relatively low (less than five feet high). At others, banks are high (15 to 20 feet) and short (e.g., 50 feet). At many sites, if erosion remains unchecked, the banks will continue to erode rapidly, perhaps increase in size, and supply large quantities of sediment to the channel.

Clancy Creek has a serious sediment pollution problem, stemming from dredge mining and perpetuated by heavy grazing. Figure II-4 shows areas (sites 1-5) with serious bank and channel problems. A detailed survey of those areas is needed to refine cost estimates and work plans. Most of the problems are along areas extensively dredged for placer gold. Eroding banks up to 30 feet high are major sources of sand and gravel.

Warm Springs Creek has a few seriously eroding banks that deserve attention and several small braided sections that were apparently destabilized by the floods in 1975 and 1981. Figure II-4 shows some problem areas (sites 1-5) along this creek, but a more-detailed survey is needed to locate specific problem sites and design remedial treatments.

Causes of Bank Erosion.

Several factors create the relatively high rate and extent of bank erosion along Prickly Pear. In many places the stream's banks are composed of the inherently weak, fine-grained (sandy) materials common in the Helena Valley. Below East Helena the average grain size of the bank materials decreases downstream fairly systematically. Where weak bank materials coincide with with heavy grazing, the banks are highly susceptible to erosion during even moderate floods. The destabilization of banks resulting from erodible bank materials in combination with land-use problems is found along short stretches of Prickly Pear from its headwaters to its mouth, but is especially common below East Helena, where heavy grazing has removed riparian vegetation, broken down banks, and accelerated bank erosion.

Heavy livestock grazing also contributes to bank erosion along portions of the lower three miles of Warm Springs Creek and the lower four miles of Clancy Creek. Here, grazing has prevented or slowed the regrowth of riparian shrubs and grass.

A large body of technical literature has documented the impacts of grazing on riparian and aquatic ecosystems (Platts 1978, 1979, Menke 1978, Marcuson 1977, Hayes 1978, Lusby *et al*. 1971). Armour (1977), for example, noted that cropping of streamside vegetation can not only promote erosion and sedimentation, but decrease shading. The concomitant increase in water temperatures may lower trout reproduction and the numbers of aquatic insects comprising the trout food base.

The riparian vegetation near many residences has been removed or converted to lawns and small pastures. The streambanks are consequently destabilized and more subject to erosion or mass wasting.

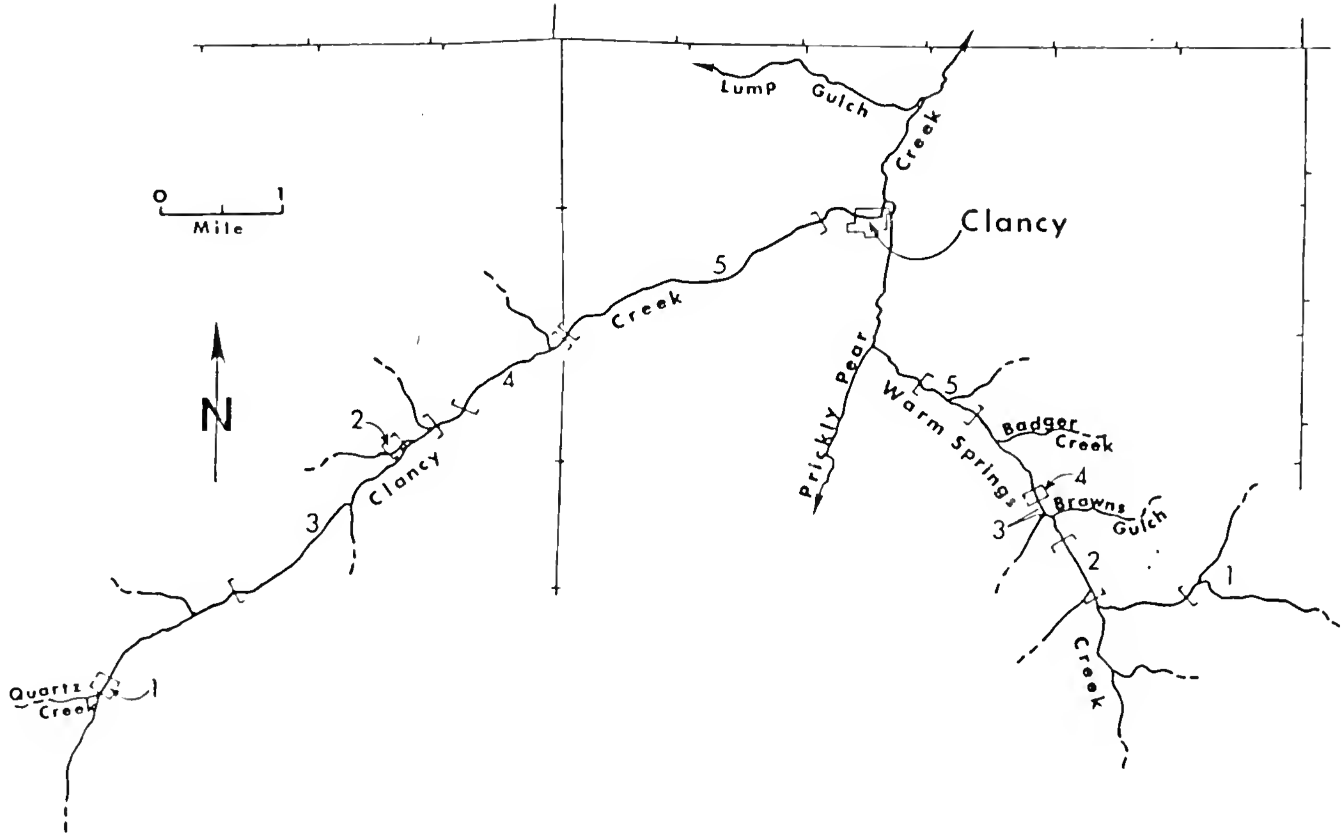


Figure II-4 Problem sites along Clancy and Warm Springs Creek.

Channelization, mostly above East Helena, also causes bank erosion. Beginning with railroad construction in the late 19th century and continuing with the construction of Highway 91 and Interstate 15, Prickly Pear Creek has been systematically shortened and straightened. Even before Interstate 15 was built, Bishop (1962) reported that the total length of Prickly Pear Creek had been shortened by three miles.

The straightened sections have typically been cleared of mid-channel obstructions, and bends and meanders have often been armored with riprap, preventing the establishment of undercut bank areas. This shortening and straightening has led to increases in the erosive forces of the creek, causing more extensive bank erosion as the stream cuts into bends unable to withstand the increased force of the water.

An example is in Channel Reach 9, where channelization has confined the stream to a very narrow corridor bounded by steep, easily erodible materials. Attempts by the stream to adopt a more sinuous course have led to extensive bank erosion and slumping.

The abandoned Burlington Northern railroad right-of-way between Montana City and Jefferson City has contributed to water pollution and bank instability in the Prickly Pear watershed. The railroad closely parallels the stream, confining it to a straight, narrow channel along the highway. In many areas, the railroad bed is constructed of slag material from the East Helena (ASARCO) smelter. This material is chemically inert, but its texture and particle size provide a poor medium for the establishment and growth of vegetation. During floods, the railroad bed is often severely eroded. In a few areas the bed has been completely lost, leaving rails and ties hanging unsupported over the stream.

Burlington Northern is removing ties and rails and selling the right-of-way. In some areas the stream could be allowed to occupy its former channel by removing the railroad bed where it confines the stream. Land-use and property-owner concerns, however, could prevent reestablishment of the natural stream channel.

Factors Eliminated as Significant Causes of Bank Erosion.

Two other possible sources of channel instability and bank erosion--increases in bed-material sediment supply and downcutting--are not significant at most locations along Prickly Pear Creek.

In some streams, an excess of bed-material sediment from the stream's headwaters or major tributaries leads to channel widening and increased bank erosion. If the increase in sediment load exceeds the channel's ability to move the material downstream, the channel will widen with bank erosion becoming more prevalent. In some extreme cases the channel will clog with sediment and branch repeatedly, forming a multiple, braided pattern.

Only a small percentage (less than five per cent) of the main Prickly Pear channel displays a genuinely braided pattern (at bankfull flow) with clear evidence of bed build-up. Most of these braided reaches are north of East Helena. Other than these few braided segments, the stream has a well-defined, single channel that has not recently become shallower and broader through depositional build-up of the bed.

Spring and Clancy creeks, which occupy drainages that have been drastically disturbed in the past by hard rock and dredge mining, have braided channels in places, suggesting excess supply of bed-material sediment. If these tributaries were delivering coarse-grained sediment beyond the transport capacity of the main Prickly Pear channel, pronounced wedges of sediment would accumulate near the confluences of these streams.

However, there is no appreciable change in channel shape or slope (gradient) on Prickly Pear below the mouths of Spring and Clancy creeks. This is because the bulk of the sediment supplied by these streams is sand-sized or finer and is capable of being transported by Prickly Pear without bed build-up. This fine-grained sediment creates water quality problems such as excessive turbidity and high suspended-sediment concentrations, decreasing the quality of aquatic habitat, but does not contribute significantly to downstream bank erosion or channel stability problems.

Downcutting is not a serious problem on Prickly Pear, despite the extensive channelization. A comparison of the 1969 channel (surveyed at the time of interstate highway construction) with the present channel shows that the stream bed between Jefferson City and Montana City has not down-cut significantly since channelization. This is probably because the bed-material has become coarser in response to the increased erosive power of channelized flow, inhibiting downcutting. More importantly, granitic bedrock underlies much of the upper drainage, and commonly crops out in the channel, limiting the extent of downcutting. Numerous large culverts further lock the channel in place.

WATER QUALITY.

Water pollution in Prickly Pear Creek has damaged aquatic life and reduced trout populations. In its 1981 report to the Prickly Pear Task Force, the Montana DHES identified three major types of water pollution in Prickly Pear Creek:

> fine-sediment pollution from disturbed tributaries, from bank erosion along the main channel, and to a lesser extent, from the City of Helena sewage treatment plant;
>
> ammonia, primarily from the City of Helena sewage treatment plant; and
>
> heavy metals and acid mine drainage, primarily from abandoned mines in the Spring Creek drainage above Jefferson City.

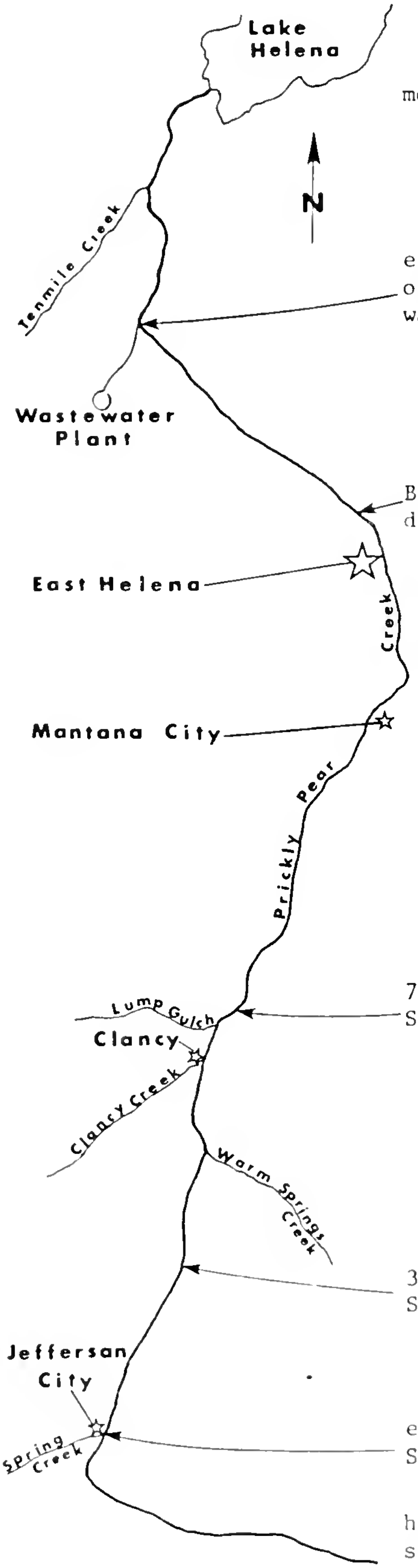
The impact of the heavy metals was studied by the U.S. Environmental Protection Agency (1982). The Montana DHES and U.S. EPA reports, particularly as they relate to the Prickly Pear trout fishery, are summarized in the following discussion. Figure II-5 summarizes water pollution problems affecting Prickly Pear Creek.

Suspended Sediment.

Seasonal surges of silty water during snowmelt are normal even in the best trout streams. Trout have adjusted their spawning and egg incubation periods to cope with these recurring periods of sedimentation. Unseasonal or highly concentrated contributions of sediment, however, can be extremely harmful. In the worst case, abrasion caused by fine sediment can irritate or irreparably damage certain aquatic insects and the gill structures of trout. At lesser, yet elevated concentrations, trout eggs and many bottom-dwelling organisms may suffocate beneath the sediment deposited on the channel bottom.

The productivity of a fishery is highest when the concentrations of total suspended sediment are below 25 milligrams per liter (mg/l); any stream in which this concentration exceeds 80 mg/l is unlikely to support a good fishery (U.S. Department of the Interior 1968). The 1981 Montana DHES report suggested that the Prickly Pear drainage below Spring Creek, including its tributaries (Spring, Warm Springs, Clancy, and Lump Gulch creeks,) produces sediment above optimal levels for trout, with 25 mg/l frequently exceeded and 80 mg/l occasionally exceeded.

Figure II-5 A Summary of Water Pollution Problems Affecting Prickly Pear Creek.



LOCATION	DESCRIPTION OF PROBLEMS
mouth of stream	
	high ammonia toxicity; high suspended sediment values
entrance of City of Helena treated wastewater	
	year-round resident fishery absent due to chronic summer dewatering
Burnham irrigation diversion	
	heavy metal toxicity - "recovery zone", toxic impacts from Spring Creek continue to lessen. abnormal suspended sediment values, some from Spring Creek; in-channel and tributary contributions increase
7 mi. below Spring Creek	
	heavy metal toxicity - "transition zone", toxic impacts from Spring Creek moderate abnormal suspended sediment values from Spring Creek and some in-channel and tributary contributions
3 mi. below Spring Creek	
	heavy metal toxicity - "impact zone"; abnormal suspended sediment, values, mostly from Spring Creek
entrance of Spring Creek	no major impacts
headwaters of stream	

Sediment in the Prickly Pear drainage originates almost entirely from non-point sources--unstable banks, abandoned mine dumps, breached settling ponds, and eroding sections of channel. A major point source of sediment is the City of Helena sewage treatment plant. Periodic flushing of sediment from behind the ASARCO dam in East Helena also adds to the problem. Several headwater tributaries are sources of fine sediment in the Prickly Pear drainage. Limited sediment sampling by the Montana DHES (1981) indicated that Spring, Clancy, and Warm Springs creeks contribute significant amounts of fine sediment to Prickly Pear.

While quantitative information on the relative importance of various sediment sources in the drainage is not available, it is very likely that fine sediment generated by bank erosion is the dominant overall source, especially downstream from East Helena.

Human activities have altered the natural course of the stream and removed its riparian vegetation, contributing to many of these sediment sources. The gradual but persistent destruction of ideal fish habitat upstream from East Helena is paralleled by corresponding increases in the erosive force of the stream, contributing to sediment (and channel instability) problems for both trout and people.

Ammonia.

Ammonia, a by-product of protein digestion, is a normal component of human sewage. In its un-ionized form, ammonia is toxic to trout at very low concentrations--0.016 mg/l (U.S. Environmental Protection Agency 1976). Elevated water temperatures and pH values increase the levels of un-ionized ammonia relative to the ionized ammonium form (Thurston et al. 1974).

The trout fishery of Prickly Pear Creek has been damaged by one principal source of ammonia: the City of Helena wastewater treatment plant, which discharges its effluent to the stream through a ditch. Although the City probably meets the standards in the state's discharge permit, the result is high concentrations of un-ionized ammonia that trout are unable to tolerate.

The City of Helena wastewater discharge is large relative to the flow of Prickly Pear Creek. The City provides treatment comparable to that of other large Montana cities, but most of those plants discharge into rivers with higher assimilative and dilution power. During peak irrigation periods, the Helena discharge contributes much (about one-third) of the flow of lower Prickly Pear Creek. Plant effluent typically contains un-ionized ammonia at levels seven times higher than the 0.016 mg/l which is toxic to trout, leading Water Quality Bureau biologists to conclude

(Montana DHES 1981):

> It is very likely that ammonia is restricting the growth and propagation of fish and other aquatic life in Prickly Pear Creek from the point of entry of the Helena sewage treatment plant discharge downstream to Lake Helena. Together with the dewatering problem, it is the primary reason that this reach of stream is not recognized as having a fishery potential...

The Montana DHES (1981) also concluded that another possible ammonia source, the Hillbrook Nursing Home at the mouth of Warm Springs Creek, has a negligible effect on Prickly Pear Creek's fishery.

Nor has the ammonia contributed to Prickly Pear by the City of East Helena sewage lagoon discharge significantly affected the fishery of the stream. The recently completed lagoon expansion provides retention times sufficient for ammonia to break down into less harmful compounds. Furthermore, the lagoon's discharge is quite small relative to the normal assimilative or dilution capacity of Prickly Pear Creek. During the summer, most of the lagoon's overflow is directed into irrigation ditches soon after it reaches the creek.

Heavy Metals and Acid Mine Drainage.

Since the onset of hard rock mining activities in the mid-1860s, Prickly Pear Creek has been subjected to high levels of heavy metals. Some of these metals, particularly copper, zinc, and cadmium, are toxic to trout at minute concentrations--in the range of 0.001 to 0.01 mg/l (U.S. Environmental Protection Agency 1980a). Heavy metals are most toxic to trout in acidic solution. In the Prickly Pear drainage, acid is produced when sulfur-bearing ore is exposed to water and air.

Before the 1970's, the ASARCO smelter at East Helena discharged heavy metals into the creek. Recent changes in the plant's operation (notably installation of a recirculation plant for both cooling and process water), have significantly reduced the amount of heavy metals entering the stream's surface water. However, the chronic seepage of wastes into the adjacent surface and ground water continues. The magnitude and effects of this seepage have not been quantified, but are presently under investigation by the Montana DHES.

The conditions causing heavy metal problems in Prickly Pear Creek immediately below Spring Creek remain unchecked. This year-round discharge of acid-mine waste significantly reduces the trout fishery through an "impact zone" which extends at least three miles below the confluence with

Spring Creek (U.S. Environmental Protection Agency 1982). The "recovery zone" extends downstream to Lump Gulch Creek (figure II-5). The dilution provided by this tributary, as well as the additions of Warm Springs and Clancy creeks, which enter just above Lump Gulch, mitigates the effects of the heavy metals. The "zone of total recovery", however, is further downstream, perhaps beyond East Helena.

Numerous unsealed adits, mine dumps, and breached settling ponds contribute to water quality problems in the Spring Creek drainage (Stiller and Associates 1983). These sources of heavy metals, sediment, and acid drainage must be reclaimed if water quality in Prickly Pear Creek is to be improved in the upper drainage.

DEWATERING.

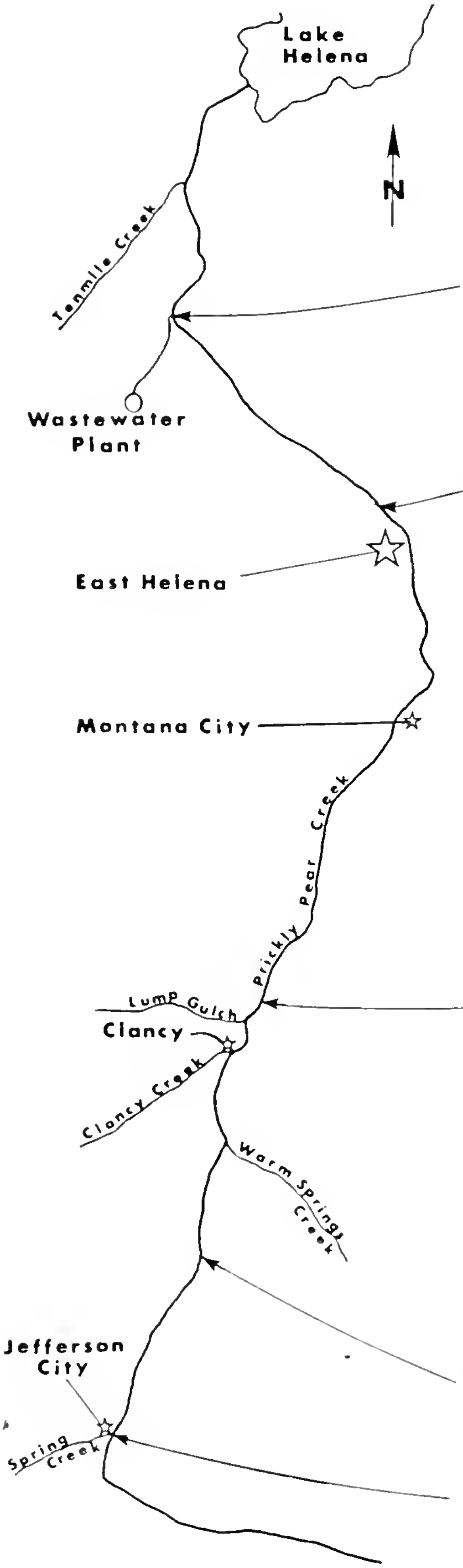
In a typical year, there is not enough water in Prickly Pear Creek to satisfy the demands of all agricultural users in the Helena Valley. Below East Helena the stream is overappropriated, lacking sufficient water to fulfill the demands of those who have rights to divert irrigation water. During normal summers about three miles of the stream are completely dewatered below the Burnham diversion approximately 1.5 miles north of East Helena (figure II-1, location D). From this point to Lake Helena, the stream is gradually recharged by irrigation returns, springs, ground water infiltration, and the City of Helena sewage treatment plant discharge.

In normal summers the segment of stream below the Burnham diversion never regains enough flow to sustain a viable resident trout fishery. Absence of streamflow also reduces or eliminates streambank vegetation, contributing to channel erosion and instability in channel reaches 13 and 14. Above East Helena, total dewatering has never been a serious threat because water demands are minimal in this steep, mountain-valley area.

TROUT POPULATIONS.

The impacts to aquatic habitat described above include: pollution by ammonia, heavy metals, and sediment; and lack of sufficient water. Not surprisingly, Prickly Pear does not support a healthy fishery for most of its length. Figure II-6 summarizes resident fish populations and the impacts causing their depletion.

Figure II-6 A summary of Present Resident Fish Populations and the Impacts Causing Their Depleted Status.



LOCATION	FISHERY STATUS	IMPACTS
mouth of stream to entrance of City of Helena treated wastewater	no year-round resident fishery	1) ammonia 2) dewatering 3) sediment 4) habitat losses
entrance of City of Helena treated wastewater to Burnham irrigation diversion	year-round fishery only during years of abnormal summer precipitation	1) dewatering 2) habitat losses 3) sediment
Burnham irrigation diversion to 7 mi. below Spring Creek	below optimum rainbow and brown trout fishery	1) habitat losses 2) sediment 3) toxic metals
7 mi. below Spring Creek to 3 mi. below Spring Creek	significantly depleted rainbow and brook trout fishery	1) toxic metals 2) habitat losses 3) sediment
3 mi. below Spring Creek to entrance of Spring Creek	no year-round resident fishery	1) toxic metals 2) sediment 3) habitat losses
entrance of Spring Creek to headwaters of stream	normal brook trout population	

Approximately one-half of the total length of the mainstem of Prickly Pear Creek is inhabited by trout on a year-round basis. But even where permanent habitation exists, trout productivity is below optimum levels, with the exception of the segment above the confluence with Spring Creek. Here, in a basically unaltered segment of the stream, small brook trout in the range of four to eleven inches are found in densities approaching 1,000 fish per acre (Hill and Greason 1981).

Immediately below the confluence of Spring and Prickly Pear creeks, the number of brook trout in the stream declines sharply, to at best 250 fish per acre (Hill and Greason 1981). Even this low number of trout may suggest a higher quality of fishery in this segment than actually exists. Fish may inhabit this section only when the water quality impacts from Spring Creek are not severe. The study was conducted in autumn, when groundwater levels were low and snowmelt was not contributing to surface discharges from the Spring Creek drainage.

Another study conducted that spring (Knudson 1981) found that cutthroat trout placed in cages immediately below the confluence of Spring Creek all died within 24 hours. Four miles below Spring Creek, all of the test fish died within 96 hours. All of the "control" fish in cages above Spring Creek survived. Even though cutthroat trout may be less tolerant of metal toxicity than the resident brook trout and placing fish in cages may impose abnormal stress, it is apparent that springtime sediment and heavy metals in the "impact zone" of Prickly Pear Creek just below Spring Creek prohibit year-round habitation by trout.

A fish survey conducted by the U.S. Environmental Protection Agency (1982) supports this conclusion. The investigation, conducted in August, found fair numbers of trout in the impact zone below Spring Creek. However, small riffle-dwelling fish of the sculpin family (Cottus spp.), abundant above Spring Creek, were found only in the recovery zone, seven miles downstream from Spring Creek. Sculpins are intolerant of heavy metal pollution and are less mobile than trout. They are therefore less likely than brook trout to move in and out of a stream segment affected by a pollutant. Their absence suggests the presence of a chronic water quality problem. The Montana DHES (1981) found a severe pollution problem in this stream segment; a diatom diversity index (which measures the diversity and abundance of certain algal communities) rated this segment "poor" compared to "good to excellent" for Prickly Pear Creek above Spring Creek.

Although the U.S. Environmental Protection Agency (1982) did not make an estimate of trout numbers, it found that rainbow trout began to be a significant portion of the trout fishery about 2.5 miles below Spring Creek. While

brook trout have almost exclusive title to the upper portions of the impact zone, rainbows are more than twice as common as brook trout at the lower site. In the recovery zone, seven miles below Spring Creek, brook trout are almost completely replaced by almost equal numbers of rainbow and brown trout.

The only other segment of Prickly Pear Creek with previous estimates of fish populations is near Montana City, approximately nine miles below the entrance of Spring Creek. From 1967 through 1972, yearly fish surveys were conducted in this segment. These estimates were part of a study that evaluated habitat mitigation during construction of the interstate highway (Workman 1974). (Further discussion of the habitat implications of this study are presented in Chapter III.)

The final population estimate (in 1972) was 79 rainbow and 90 brown trout per acre, with an average fish size much larger than that found above Spring Creek. The 1972 values were similar to those made in 1967, one year before the construction of the highway. These data were used, in part, to estimate a trout standing crop of 73 pounds per 1,000 feet for this segment of Prickly Pear Creek.

This value is about average for trout streams in Montana surveyed by DFWP in 1978 (Holton 1983). The maximum surveyed value for Montana streams in 1978 was 451 pounds of trout per 1,000 feet of stream.

The Montana City segment of Prickly Pear Creek is midway into the recovery zone from the problems caused by Spring Creek acid mine waste. This segment is also in an area where channel alterations caused by interstate highway construction were mitigated by the Workman project. It is therefore one of the best segments for trout in Prickly Pear Creek. Above this site the acid mine waste and habitat worsen (until above Spring Creek). Less than five miles below the site, dewatering and ammonia pollution prevent the establishment of any permanent resident fishery.

The trout fishery of Prickly Pear Creek therefore ranges from about average for Montana trout streams (within the relatively small recovery segment) to no fish at all in the most severely degraded segments.

The dewatering and ammonia impacts that limit the resident fishery also affect migration attempts by spawning trout from Hauser Reservoir. Each spring, for one to two months, large rainbow trout seek spawning sites in the tributaries of the Missouri River, an effort repeated in the autumn by brown trout. Even if these spawners are able to overcome the ammonia from the City of Helena sewage treatment plant, the summer dewatering below the Burnham diversion either dessicates the fertilized eggs or kills the

young, recently-emerged fish.

The spawning success of these fish could be high in the recovery segment above East Helena. However, the ASARCO dam at East Helena blocks spring and fall spawning of trout which move upstream from Lake Helena. Before the 1981 flood which destroyed the dam, a fish ladder had been constructed, but it is not known how successfully it was used. After the 1981 flood, ASARCO reconstructed the dam to maintain the water surface of Prickly Pear at the same elevation as the cooling ponds adjacent to the stream, to prevent down-gradient leakage from the ponds into the stream. The dam is also a roadway and bridge to the plant and allows diversion of water for local users.

Finally, dredge and placer operations have historically been concentrated in the portion of Prickly Pear Creek above East Helena. In this area, many unstable sloughing spoil piles remain. Although construction of Interstate 15 has partially mitigated these impacts, the unsightly spoil piles and disarranged channel bottoms still affect aesthetics and fish habitat in many stream segments.

CHAPTER III.

ANALYSIS OF PROBLEMS AND POTENTIAL SOLUTIONS

BANK STABILIZATION and SEDIMENT CONTROL

Erosion and sedimentation problems, in addition to limiting the stream's aquatic productivity, affect private, municipal, and industrial stream users. These problems affect the widest range of users and, in general, appear most within the Districts' authority and problem solving resources.

The erosion of streambanks is a significant water resource problem in the United States. Of the nation's nearly 3.5 million miles of rivers and streams, roughly 575,000 miles suffer from bank erosion (U.S. Army Corps of Engineers 1981). Severe erosion requiring treatment occurs on roughly two per cent of the total length of streambank. This erosion is responsible for about $250 million annual damage in the form of loss of land, bridges, roads, and other civil works. About $1.1 billion is spent annually to protect streambanks and inhibit erosion in the United States (U.S. Army Corps of Engineers 1981).

In the Prickly Pear drainage, serious erosion is occurring along approximately 6.5 miles of streambank, compared to the 5.6 miles determined by the 1980 physical streambank inventory (Montana DHES 1981). The difference in the two values is due to the increase in erosion caused by the 1981 flood and the methods used to inventory and compile erosion data.

Stabilization of eroding banks and shifting stream channels in the Prickly Pear drainage is needed for three reasons:

to protect roads, bridges, fences, buildings, cropland, and other features of value;

to control pollution of the stream by fine sediment, which damages fish and lowers the overall quality of aquatic habitat; and

to control the amount of coarse sediment supplied to the stream where it causes buildup of the stream bed, reduces the capacity of the channel to transmit flood flows, and creates lateral instability of the channel.

On Prickly Pear Creek, the first two reasons are very important, the latter less so because, as described earlier, only a few segments of the creek have a seriously unstable channel.

Methods for Stabilizing Banks and Controlling Sediment.

The first step in design of effective bank protection is to recognize the causes of erosion at a site. The second step is to select appropriate methods to inhibit the processes responsible for erosion. Three basic approaches to stabilizing banks are possible:

> structural methods, which include the use of revetments (riprap, stone-filled wire baskets called gabions, and concrete) to "freeze" banks in place, and structures (jetties, spurs, or dikes) which deflect erosive flows away from banks;
>
> non-structural methods, which include bank reshaping, establishment and management of streamside vegetation, and the use of natural materials (brush mats) as bank revetment; and
>
> combined methods, in which non-structural methods are used in combination with limited structural measures to provide adequate bank protection for the establishment of erosion-resistant vegetation.

Each method has advantages and disadvantages. Purely structural measures are generally costly to construct and maintain and, if relied on extensively, may create secondary aesthetic and ecological impacts. Site access by machinery and the degree of stream disturbance required for installation also limit the use of structural measures. However, properly designed structural measures provide effective bank protection. In high-energy stream situations, such as at concave banks along the outsides of bends, there are usually no good alternatives.

Non-structural measures of bank protection emphasize the use of natural materials, relying primarily on vegetation to inhibit bank erosion. In many situations the long-term bank protection afforded by healthy bank vegetation is cost-effective, providing aesthetic benefits and overall improvement of aquatic habitat (Gray and Leiser 1982, Lines *et al*. 1978).

Use of combined structural and non-structural methods recognizes the positive aspects and limitations of both.

Each of the three methods has suitable applications in the Prickly Pear drainage. A design especially suited for protecting and stabilizing banks in the Prickly Pear drainage is the use of flow deflectors (small permeable rock jetties) to inhibit bank erosion, encourage sediment deposition near the bank, and provide sufficient bank stability for successful growth of planted bank vegetation. A more detailed description of bank protection methods is given in Appendices A and B.

One way to control excessive sediment supply and transport in a stream is to trap it in basins, either natural or artificial. Downstream from East Helena are several small gravel pits, no longer in use, which could conceivably serve this purpose if the stream were routed through them. Located on the Burnham property near the siphon of the Helena Valley Canal, these pits are unfortunately too small to provide the retention time necessary to provide efficient capture of sediment and a long enough useful life. They would fill with sediment in three to ten years.

Determination of Work Priorities.

High suspended sediment levels are contributed by many non-point sources and, as such, require comprehensive treatment and land use management throughout the drainage in order to achieve control. Along the Prickly Pear mainstem, many individual sites--mostly eroding banks--are non-point sources of sediment. Each of these sites was ranked according to the magnitude of the problem (length and height of eroding bank), its significance as a sediment producer, and whether or not the erosion was a continuing problem meriting treatment. A set of work alternatives and their costs is provided in the list of recommendations (see Chapter IV). Detailed cost information is given in Appendix D.

Sites where erosion threatens houses, bridges, roads, and other civil works were generally assigned "moderate" to "high" priority, because they merit the quickest treatment. Eroding banks which supply large amounts of sediment to the channel were also given moderate to high priority.

Sites with moderate and high priority have bank heights ranging from 3 to 20 feet and are often located in bends or near channel constrictions. If untreated, these sites will continue to erode until the rate of bank failure exceeds the rate of basal removal by fluvial entrainment. A new bank angle and, perhaps, a new channel width are established. During this process significant amounts of bedload and suspended load may be supplied to the downstream channel, especially in reaches with steep, high banks.

Areas having "low" priority generally have low banks (one to three feet), are usually located in straight channel segments, and in most instances supply relatively small amounts of sediment to the channel. Low priority areas may eventually heal themselves through natural establishment of riparian vegetation--a process which could be assisted by planting.

Table C-1 in Appendix C summarizes site rankings and recommended treatments for individual problem sites.

AMMONIA.

Along with suspended sediment, ammonia pollution is a major water quality problem in Prickly Pear Creek. Measures which could prevent ammonia from entering Prickly Pear Creek include changing the point of discharge of treated water and upgrading the City of Helena's wastewater treatment.

The City's waste discharge presently enters Prickly Pear Creek in the NE 1/4, section 9, T.10N., R.3W., approximately 4.5 miles above Lake Helena (figure II-1, location E). Below the discharge is a series of large irrigation drain ditches that could, with minor rerouting, convey the treated wastewater directly to Lake Helena. Changing the point of discharge to one or more of these ditches would remove the impacts from the stream and pass them on to Lake Helena, with its larger assimilative capacity. However, the closest ditches are in sections 33 and 34, T.11N., R.3W., approximately 1.5 to 3 miles from the present point of discharge. This option would therefore require the construction of conduits or ditches capable of conveying the design capacity of the sewage treatment plant, about ten cfs.

Upgrading the City of Helena waste treatment facility could take one of two forms: in-plant treatment, in which ammonia would be converted to less toxic compounds; or rapid infiltration, in which the discharge would be percolated through a soil layer and breakdown would occur before the discharge enters the stream. Either of these treatments would substantially reduce the ammonia concentration of the city's waste discharge. The four types of in-plant treatment and rapid infiltration (land treatment) are discussed below. Cost data were taken from the U.S. Environmental Protection Agency (1980b).

Break-point chlorination.

Perhaps the most promising form of in-plant treatment would be adjustment of the wastewater's pH (the acid-base

balance) toward acidity, followed by break-point chlorination. Increasing the acidity of the water would push the equilibrium between ammonium ion and ammonia in the direction of ammonium, which is less toxic to fish. The ammonium would be oxidized by chlorine to nitrogen gas, with chloroamines as by-products. The term "break-point" refers to applying just the right amount of chlorine so there is little left over. Control of pH would be provided by the addition of carbon dioxide. Capital costs could be under $1 million, but operating costs could reach $500,000 annually.

Ammonia stripping.

Another in-plant treatment, ammonia stripping involves passing high-ammonia water through a packed tower with a counter-current flow of air. The ammonia passes from the surface of the water droplets to the air. Control of pH in this case would be away from acidity, to increase the relative fraction of ammonia in the un-ionized form. Ammonia stripping, although technically feasible, is seldom used because of its high capital and operating costs. Freezing problems in Montana's cold climate could also render the process ineffective.

Ammonia Removal and Recovery Process.

Freezing problems can be solved using a variation of ammonia stripping called Ammonia Removal and Recovery Process (ARRP), in which the ammonia is recovered from the air after stripping. Two towers are employed: one strips ammonia from the high pH wastewater; the second dissolves the ammonia in water for recovery.

ARRP is a technically feasible but relatively untried process with high costs for both capital equipment and operation. For a wastewater stream the magnitude of Helena's, capital costs would be on the order of $3 million; annual operating costs could reach $400,000.

Ion exchange.

Ion exchange, another type of in-plant treatment, passes filtered water through a bed of material such as clinoptilolite, a zeolite which adsorbs ammonium ions. Because of high costs, this process is seldom used; capital costs would exceed $2 million, and annual operating costs could be as high as $200,000. The cost of filtration would be extra.

Land treatment/rapid infiltration.

Rapid infiltration is currently being used in Montana waste treatment facilities, including Bozeman's. Once land for the percolation fields has been purchased (the Bozeman site required about 120 acres) and necessary excavation and underground piping have been completed, operation and maintenance costs are low. Other advantages of this treatment system are that the suspended solids and "oxygen-demanding" components of the waste are also substantially reduced. A drawback is the potential for contamination of ground water with nitrates, one of the breakdown products of ammonia. This problem can be reduced by the installation of underdrains. In addition to the cost of land, capital costs could exceed $1 million, with operating expenses up to $100,000 annually. The City of Bozeman capital costs totaled about $7 million.

Summary.

The problem of high ammonia concentrations in the effluent of the City of Helena wastewater treatment plant can probably be solved, but not cheaply. Of all the methods described, the least expensive would be either break-point chlorination or land treatment. Bench-scale testing of break-point chlorination with pH control could lead to a cost-effective solution to the ammonia pollution problem. These measures, however, are likely beyond the scope and financial abilities of the Conservation Districts.

HEAVY METALS.

The Office of Surface Mining (OSM) and the Montana Department of State Lands (DSL) have taken initial steps to control pollution and reclaim damaged land in the Corbin-Wickes area. DSL petitioned OSM for funds under the Abandoned Mine Lands Reclamation Program to reclaim the abandoned mines, tailings, and settling ponds which affect Spring, Corbin, Alta, and Clancy creeks. OSM funded preparation of a reclamation plan for the abandoned mines and related facilities, recognizing that the abandoned mine facilities' heavy metal contamination of ground water and airborne sediments pose a serious threat to human health.

The reclamation plan for abandoned mines in the Prickly Pear drainage (Stiller and Associates 1983) included specific reclamation and abatement plans for the Alta, Bertha, Mt. Washington, Blue Bird, Minah, and Gregory mines, Corbin and Alta creeks, and Corbin Flats.

Two general strategies for addressing water quality problems were proposed:

prevention of ground and surface water from coming into contact with toxic materials such as pyritic waste dumps and underground mine workings; and

treatment of degraded ground or surface water to improve its chemical and physical qualities.

Other measures were also discussed: hydraulically sealing discharging adits; revegetation, treating, and stabilizing waste piles; and burying problem wastes. DSL and OSM are considering whether to act on the recommended reclamation measures or investigate other alternatives.

Centennial Minerals, Ltd. is studying the economic feasibility of reprocessing the tailings at the Bertha and Alta mine dumps. The Alta mine dump contains 279,000 tons of material that could be processed with cyanide through the heap leaching process. The Bertha Mine dump has 41,000 tons of mill tailings and 24,000 tons of dump material which are not economical to process at this time (Rudio 1983). It may be economically feasible to remove the Alta mine dump, truck the material to facilities at Whitehall for reprocessing, and reclaim the disturbed area.

State and federal investigations may lead to a large-scale reclamation project to lower concentrations of metals in Prickly Pear Creek and its tributaries. The cost of such a project, although not quantified, would be far more than the Conservation Districts could afford.

FISH and AQUATIC HABITAT ENHANCEMENT

Treating water quality problems could be complemented by other measures to improve the Prickly Pear fishery. The segment of Prickly Pear Creek from East Helena to just above Clancy has the potential to provide a much better aquatic habitat and fishery. Trout productivity could be enhanced and sediment problems originating within this segment reduced by three methods:

establishing overhanging cover along banks by planting shrubs and other riparian vegetation;

creating pool-riffle contrasts in areas of high stream gradient by installing flow deflectors or judiciously placing mid-channel obstructions such as boulders; and

establishing new habitat by lengthening the stream

channel, and then using the above techniques.

Table III-1 and figure III-1 show the sections of Prickly Pear Creek where enhancement of trout habitat would produce the greatest (and most cost-effective) results. The sections are listed in order of priority--downstream to upstream, because upstream sections have poorer water quality than downstream sections.

TABLE III-1.

Stream Segments Recommended for Fish-Habitat Improvements

Problem sites selected for habitat improvement	Channel Reach	Length (feet)	Comment
19-2-EB to 19-2.3-EB	10	2400	Just upstream of McClellan Creek.
24-6-EB to 23-12-R	9	4300	Frontage road bridge to just below gaging station.
30-1-A to 30-6.1-EB	6	2400	Clancy town park site.
33-9-R to 32-9-A	North half of 5	3000	West side of I-15 above Clancy.

Bank Vegetation.

Riparian vegetation can be used as a vital component of natural protection for sloughing streambanks throughout the Prickly Pear Creek drainage (see Appendices A and B). The reestablishment of riparian vegetation to increase fish habitat quality has been successfully employed on streams in Montana and throughout the Pacific Northwest for many years. For example, trout abundance increased more than three times after the addition of brush cover to banks along only five percent of one Montana stream segment (Boussu 1954).

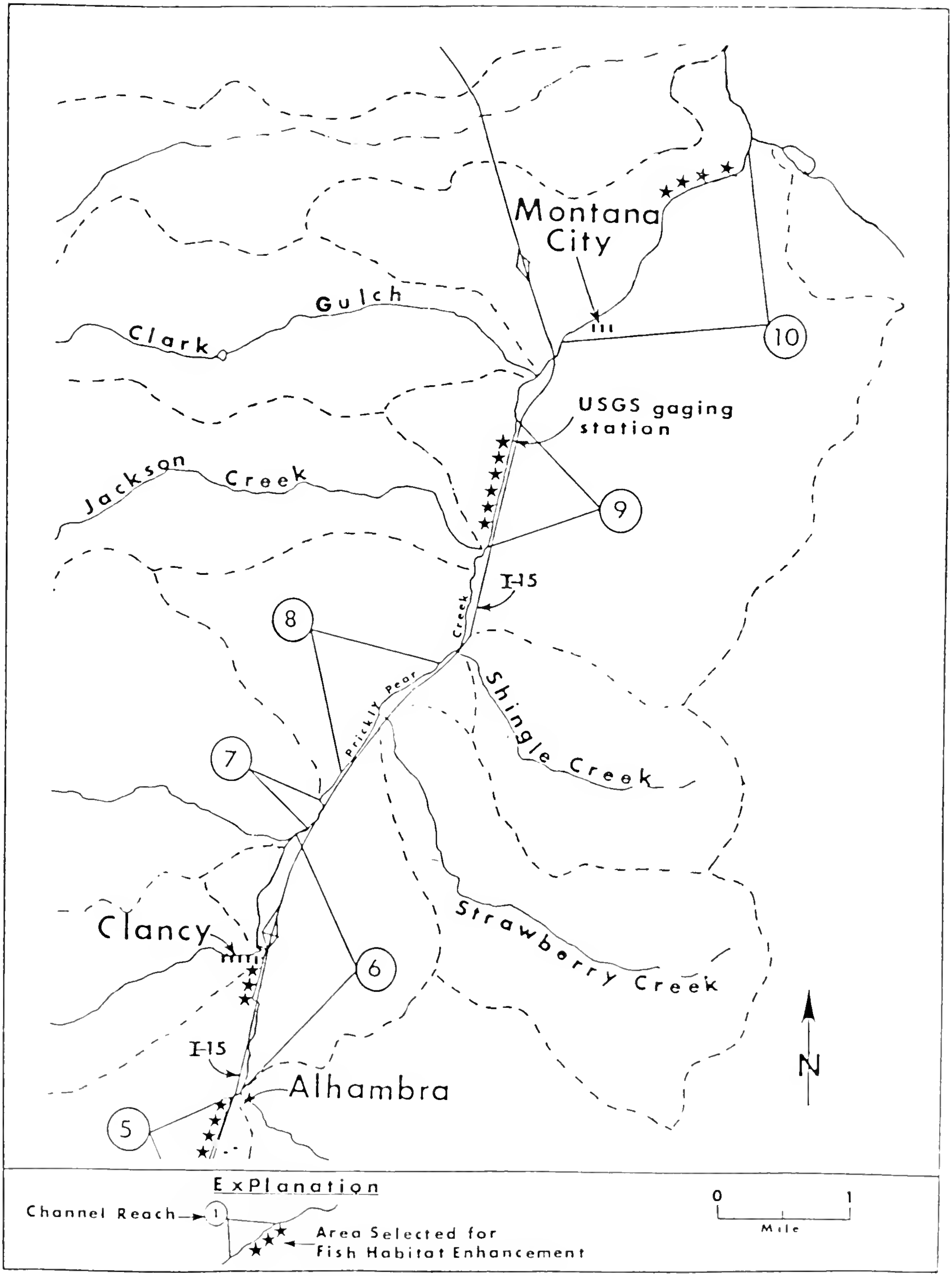


Figure III-1 Stream Segments Selected for Improvment of Fish Habitat.

The success of vegetation for stabilizing streambanks in high-energy environments (especially bends) is dramatically increased by backsloping and armoring the toe of the bank with heavy riprap (Workman 1974, Klingeman and Bradley 1976). However, heavy armoring should be used only where absolutely necessary, since it usually prevents the establishment of undercut fish habitat. If carefully placed, large angular riprap may provide some fish habitat.

Instream Habitat Improvements.

Flow deflectors, small rock jetties which can be used as bank protection, have created and improved fish habitat on a variety of streams. Loss of instream habitat due to the channelization of the Weber River (as a result of highway construction) was largely mitigated through the use of flow deflection structures (Barton and Winger 1973). In Michigan, an increase in the number and size of pools created by flow deflectors resulted in a 141 per cent increase in the catch rate of trout (Shetter et al. 1949).

Along Prickly Pear Creek, prime sites for flow deflectors are in section 23, T.9N. R.3W., starting about 1,600 feet below the U.S.G.S. stream gaging station and continuing upstream to the frontage road bridge (Channel Reach 9). The upper portion of this segment also contains a site, identified as 24-7-EB in the Montana DHES (1981) physical inventory, where a natural flow deflector (bedrock outcropping) reestablished a natural stream meander.

Placing large boulders in midchannel dissipates a stream's eroding energy while creating pools and surface agitation. Random boulder clusters are relatively inexpensive, durable, self-maintaining if carefully placed, and have been used extensively on streams similar to Prickly Pear (Barton and Winger 1973, Hall and Baker 1982, Reeves and Roelofs 1982).

This method could be used at numerous locations. A good example is the segment above Clancy in section 16, T.8N. R.3W. (in Channel Reach 6); midstream boulders would reduce the velocity of the stream and create excellent fish habitat. Other areas where instream obstructions would enhance trout habitat include the segment studied by Workman (1974) and the one immediately below the Kaiser Cement Plant.

Other types of common instream habitat improvements include: log jetties, check dams, artificial bank cover structures, and gabion weirs (White and Brynildson 1967, Hall and Baker 1982, Reeves and Roelofs 1982). These structures, while normally successful on small streams, are

costly on streams subjected to the extreme forces of nature. Check dams and bank cover structures may not be successful in the Prickly Pear drainage at present. Coarse sediment loads, while not extremely high, are probably sufficient to greatly reduce the effectiveness and lifetime of many types of fish habitat improvements. At a few locations, check dams and bank cover devices might be used successfully and should be tested. Depending on their success and the elimination of excessive sediment supply to the stream, more habitat structures could be constructed. Appendix C includes details of recommended fisheries habitat improvement demonstration projects for reaches 6-10.

Channel Relocation.

Much of Prickly Pear's channel from Jefferson City to Montana City has been relocated by highway and railroad construction. Returning the stream to its original meandering course in these areas would increase the amount and diversity of aquatic habitat, as well as provide a more natural appearance. Lengthening the channel may also contribute to channel bank stability because channel gradient and flow velocity would be decreased.

This method, used in Montana on the Clark Fork River (Hunt and Graham 1972), was applied on a small scale during interstate highway construction on Prickly Pear Creek in 1969 (Workman 1974). Its use as a general technique for mitigating the impacts of stream relocation caused by highway construction is commonly advocated (U.S. Department of Transportation 1979, Winters and Gidley 1981).

While this method holds promise for use at carefully selected locations, physical considerations such as topography, sediment dynamics, land use, and land acquisition limit its present applicability in the Prickly Pear drainage.

For example, the sediment dynamics of the upper drainage limit the feasibility of any extensive channel relocation. Considering the high sediment loads in Prickly Pear, it is probable that decreasing the stream's slope along a section of higher gradient stream could induce sediment accumulation, resulting in long-term maintenance problems. Currently, sediment accumulates only where valley and stream gradients are reduced (for example, in the northern half of Reach 6, between reaches 9 and 10, and behind the ASARCO dam). Reoccupation of pre-railroad and pre-interstate channels should probably not be attempted until overall sediment loads are reduced in the upper drainage.

The idea should not be dropped, however. Planning, design, and land aquisition for eventual channel relocation should begin soon. Portions of Prickly Pear between McClel-

lan Creek and the Kaiser Cement Plant, for instance, could be lengthened to improve stream habitat. There, Prickly Pear Creek is confined between the railroad and the highway. However, the right bank of the stream is relatively flat for a width of 50 to 100 feet before it reaches the steep slope leading up to the highway. Flow deflectors and gabions could be used to establish small meanders and pools. This area is also suitable for roadside parks (see Appendix C).

Other prime locations for lengthening Prickly Pear Creek are in section 9, T.8N. R.3W., near Clancy (possibly creating a community park), and in sections 34 and 26, T.9N. R.3W. In section 34, the road to Forest Park Estates could be relocated to the abandoned railroad right-of-way, allowing a portion of the stream to occupy the existing roadway. Any projects involving the Forest Park Estates road and the Clancy site would depend on acquisition of title or a right to use the railroad right-of-way.

In section 26, T.9N., R.3W. a segment of Prickly Pear Creek was cut off from the main channel during railroad construction. If the old railroad grade were breached at two places, the stream could occupy its former channel. This segment would start near site 25-9-R and return to the present stream channel near site 25-12-EB. The riparian vegetation in this abandoned channel is still very dense. Fish habitat would therefore be increased and the home located near 25-9-R better protected from floods.

The section of state land above Clancy is another area where additional stream meanders could be constructed. This area and the land surrounding the stream segments near the gaging station and the Kaiser Plant are located on public land.

REWATERING PRICKLY PEAR CREEK.

Because of the great improvements to be gained in channel and bank stability, stream and floodplain vegetation, and aquatic habitat, rewatering Prickly Pear is high on the list of long-term general problems needing correction. There is, however, no simple and inexpensive solution; of all the problems affecting the fishery of Prickly Pear Creek, dewatering will likely be the most difficult to solve.

Because the Prickly Pear Creek is overappropriated, additional water placed in the stream could be legally diverted by downstream water right holders, unless the new water was legally preserved for instream purposes. Therefore, any plan to rewater Prickly Pear must provide a legal mechanism to ensure that instream water has a right or

reservation.

The other obstacles to rewatering Prickly Pear Creek are the availability and cost of water. A flow of 20 cfs represents the bare minimum "survival" flow capable of maintaining trout populations in most sections of the dewatered reach. Thirty to forty cfs would be optimum for maintaining riparian vegetation and suitable water temperatures, as well as allowing fish to migrate (see Appendix F for additional details on flow requirements).

We investigated the technical feasibility and costs of six potential solutions to the dewatering problem: groundwater-fed sprinkler irrigation; obtaining for water from the Helena Valley Irrigation Canal; pumped storage; storage of water above headwater dams; storage in abandoned gravel pits north of East Helena; and storage in groundwater aquifers. Each of these options is discussed briefly in the following sections. Appendices E, F, G, H, and I present technical analyses of water availability, low-flow requirements in the dewatered reach, water storage capacity of Burnham's abandoned gravel pits, costs of sprinkler irrigation, and water storage in alluvial aquifers in Wood Chute Gulch.

Sprinkler Irrigation Fed by Ground Water

A sprinkler irrigation system fed with ground water could be substituted for the present surface water irrigation methods. Sprinkler irrigation provides a more efficient use of water and, if relied on more extensively in the lower Prickly Pear drainage, could eliminate dewatering in all but the driest summers.

Don Burnham, a farmer-rancher who holds the senior water right in the drainage (250 miners inches--6.25 cfs), has expressed interest in developing a sprinkler irrigation system which would eliminate his need to divert water from the stream. In exchange for assistance with a new system, he would stop diverting from his lowermost diversion point and donate his water right for instream use. Four types of problems confront this solution:

> Physical. Converting Burnham's right from an irrigation diversion to an instream right would not, even if the full 6.25 cfs were available, provide enough water in the creek to satisfy the needs of a fishery.
>
> Political and legal. In order for water right holders to donate rights to the state for instream flow benefits, Montana water law would need to be changed so the priority could be carried along with the right, thus protecting the instream flows from diversion.

Availability of ground water and impact on local wells. Sufficient ground water would be necessary to meet irrigation demand. A recent study of groundwater availability in the Helena Valley (Hydrometrics 1983) shows that much of the East Helena Valley (which includes the Burnham property) could supply large amounts of ground water. However, depending on the scale of ground water development and specific location of wells, conflicts could arise with adjacent well users. The relatively high cost of ground water development would require a detailed study of the local groundwater system to ensure water availability and to determine the potential impacts on wells in the area.

Cost of implementation. A preliminary cost estimate for a sprinkler irrigation system and groundwater supply wells is given in Appendix H. Between $160,000 and $200,000 would be needed to install a system for irrigation of 400 acres on the Burnham property.

While somewhat expensive and not without legal obstacles, this alternative is the most promising of the six options identified. However, to meet the minimum 20 cfs instream flow requirement, a water right transfer totaling 800 miners inches would be necessary. Thus several other right-holders in addition to Don Burnham would need to convert to sprinkler irrigation and transfer their water rights for instream use.

Helena Valley Canal.

The Helena Valley Canal is another possible but expensive source of water for rewatering Prickly Pear Creek. Approximately 3,000-6,000 acre-feet/year would be required annually to provide a minimum flow of 20-40 cfs for a 75-day period. This water would cost $30,000-60,000 per year, depending on the amount of water used and the rate charged. Appendix E explains the assumptions and hydrologic calculations.

Assuming funding for water purchase, several serious problems remain with using canal water in Prickly Pear. An instream water right for the flow would have to be obtained to preserve it in a downstream direction until the water reaches Lake Helena. Also, the canal currently flows at capacity to provide water to irrigators during the crucial summer months when Prickly Pear Creek is dewatered. Either canal water would have to be purchased and stored during other months, or irrigation demand on the canal during the summer reduced. If water were stored, the cost could be $2 million or more, depending on the site.

Pumped Storage.

Pumped storage could be used to store spring runoff for release during low flow periods; sufficient water is probably available (see Appendix E). After allowing for water rights withdrawals by municipalities, industry, and agriculture, and a simulated spring peak flow for the stream reach in the vicinity of the U.S. Geological Survey stream gaging station above Montana City, roughly 6,250 acre-feet would be available for diversion and storage during a typical spring. This compares favorably with the amount actually required to bring the deficit months (July, August, September) up to 17 cfs, which is about 5,130 acre-feet (see Appendices E and F.)

As previously discussed, the dewatered reach below East Helena has an instream flow requirement of 20 to 40 cfs. In order to provide this flow during the peak irrigation season, an additional 500 to 3,400 acre-feet of the spring surplus must be diverted and stored at the upstream site.

Although water is available, only one site--Clark Gulch--is topographically and environmentally suitable for pumped storage. Clark Gulch was the prime site for a dam and pumped storage for Diehl Development Corporation's proposed housing project near Montana City in the early 1970's. All other sites investigated had one or more of the following problems: poor foundation materials; inadequate storage capacity; and land-use conflicts (relocation of residences and roads).

The Clark Gulch site is on the west side of the Prickly Pear drainage, about two miles due west of Montana City. An earth fill dam 210 feet high and 1,300 feet long would store about about 20,000 acre-feet in a reservoir two miles long with a surface area of 300 to 500 acres (Montana DNRC 1974). The elevation at the site is about 4,440 feet. Depending on the location of the diversion point, the lift from the stream would be between 300 and 600 feet.

Construction of the dam and pumping system would have cost about $5,870,000 in 1974 (Montana DNRC). Maintenance and pumping would have added another $616,422 annually. The average cost per acre-foot of water--$154--would have made the project an expensive proposition. Off-stream pumped storage is not feasible for correcting the dewatering problem in the near future.

Storage in Abandoned Gravel Pits.

Several small abandoned gravel pits on the Burnham property could be used for storing spring runoff. These gravel pits are one-and-a-half to two miles north of East Helena, on land leased to Helena Sand and Gravel (figure II-1). The largest pond, south of and adjacent to Prickly Pear

Creek, has a water storage capacity of 60 to 240 acre-feet, depending on whether or not an embankment is constructed (see Appendix G). By using other smaller abandoned pits further north, it may be possible to double or triple the storage volume. However, the total storage would be less than 700 acre-feet (not accounting for seepage, which could be considerable). If 700 acre-feet were stored, the continuous yield would be 20 cfs for seventeen days, only 23 per cent of the time this flow would be required for maintenance of a minimum instream flow below Burnham's diversion. Thus, storing water in the gravel pits would not provide sufficient flow to eliminate dewatering.

Storage Above Dams in Tributaries.

Storage of water above existing or new dams has limited potential: water rights from existing dams are already allotted; few suitable undeveloped sites exist; water available for storage is small; and construction of dams is very expensive. We found no suitable sites in Prickly Pear Creek and its tributaries. Most topographically feasible sites were too far up tributaries to receive an adequate source of water, or had potential land use conflicts.

If the City of Helena decides to abandon its water supply interests in the Chessman Reservoir, this water could be used to augment the summer flows of Prickly Pear Creek by discharging into Buffalo Creek and then into Lump Gulch Creek (figure II-1). Reservoir safety and the suitability of Buffalo Creek to serve as a conduit would have to be considered, as would the legal problem of transferring the City of Helena's water right to a public agency for fish and wildlife purposes, while maintaining its priority date.

Chessman reservoir stores only about 1000 acre-feet of water (its watershed is but six or seven square miles). Also, the long-term maintenance costs to keep the dam safe and operating would be substantial. Given these drawbacks, Chessman Reservoir is not a feasible source of water to augment summer flows in Prickly Pear Creek.

Wood Chute Gulch--Storage in Ground Water Aquifer.

Wood Chute Gulch, a tributary to Spring Creek, could provide water storage. This option would rely on groundwater storage rather than surface reservoir storage. Spring flows would be diverted and infiltrated into alluvial aquifers, recharging the ground-water system. Water stored in this manner would then be slowly released during the remainder of the year. The small amount of surface flow available for storage and the lack of an aquifer of suitable size, however, limit the method's feasibility. Appendix I shows that the Wood Chute drainage is not large enough to supply

sufficient water for storage and flow augmentation in Prickly Pear Creek.

Summary.

Assuming that legal obstacles to obtaining and maintaining flow for instream use in Prickly Pear Creek can be surmounted, two feasible possibilities exist for rewatering the stream:

> substitution of more efficient ground water-fed sprinkler irrigation systems for present surface water irrigation methods; and
>
> obtaining water directly from the Helena Valley Canal.

If demand for water from the canal declined to the point that even five per cent of the its capacity were available to provide instream flow, 12.5 cfs could be added to the stream. This amount, plus Don Burnham's water right (6.25 cfs) would nearly provide the minimum flow required to meaningfully rewater the stream. If demand for water from the canal remains at the canal's capacity, then construction of a reservoir (3,000 to 6,000 acre-feet) to store canal water obtained in the off-season would be necessary.

CHAPTER IV.

RECOMMENDATIONS FOR STREAM CORRIDOR MANAGEMENT

STREAM CORRIDOR MANAGEMENT.

Prickly Pear Creek's stream corridor is the relatively flat area occupied by the stream channel and adjacent streamside vegetation. The corridor varies from 30 to 100 feet wide, while the floodplain stretches several hundred to a thousand feet in width. Of Prickly Pear's total 260-square-mile-drainage area, the main stem stream corridor comprises approximately one square mile of land. Although small in size, it is perhaps the most valuable land in the drainage, a sensitive ecosystem whose health and value to humans depends highly on all land uses in the drainage.

The goal of stream corridor management is to prevent or solve stream problems created by many diverse and conflicting uses of the stream (USDA 1978). Successful stream corridor management depends highly on the recognition of common ground and the coordination and cooperation among all users.

Several examples of common ground exist in the Prickly Pear. Perhaps the best is the mutual benefit derived from protection of the natural streambank. The establishment and maintenance of streamside vegetation protects the streambank from erosion, provides fish and wildlife habitat, offers forage and shelter for livestock, and contributes to an aesthetically pleasing landscape. Private landowners, wildlife, and the public all benefit from stream management which emphasizes the importance of riparian vegetation.

Another example is the multiple benefits obtained from cleaning up the acid mine drainage and heavy metal pollution in the Spring Creek-Corbin Creek drainage. This problem affects downstream land owners (within the Spring Creek drainage, ground and surface water are badly polluted), fish which cannot tolerate the pollution, and, ultimately, the public which would use the stream more if water quality were improved.

Our proposed Prickly Pear management plan contains three elements:

general recommendations on how to address drainage-wide stream rehabilitation;

Specific policy and treatment recommendations for problem sites along the mainstem and tributaries; and

Suggested work plans for site treatment, based on three alternate levels of initial funding.

GENERAL RECOMMENDATIONS.

General Recommendation 1. **The Conservation Districts should support and assist all efforts to correct the four major problems: dewatering and pollution by heavy metals, ammonia, and sediment.**

Water quality and the trout fishery in Prickly Pear currently suffer from pollution by heavy metals between Jefferson City and Clancy, pollution by ammonia from the City of Helena sewage outfall below York Road, severe dewatering of at least three miles of the stream below East Helena, and pollution by fine-grained sediment along the entire stream. These four problems place severe stress on Prickly Pear Creek's aquatic ecosystem and limit the extent to which the stream's water quality and fish population may be restored throughout the drainage.

The cost of completely correcting any one of these problems may be beyond the scope of any grant that the Districts could obtain. Therefore, we suggest that the Districts publicize the findings of this and related studies. Obtaining reclamation funds could depend on informing the general public and governmental agencies about the potential benefits of solving these major environmental and land use problems.

General Recommendation 2. **Revegetation of streambanks should be a required component of bank protection efforts.**

Drainage-wide treatment of bank erosion and channel stability problems calls for a management strategy that recognizes the importance of restoring and maintaining healthy riparian vegetation. While structural protection will be required to assist initial revegetation at many locations, successful establishment of streambank vegetation will enhance the longevity, effectiveness, and aesthetics of any required structural improvements.

General Recommendation 3. **The Conservation Districts should request that the Montana Department of Fish, Wildlife and Parks conduct spring and fall fish population estimates at the following locations: above**

Spring Creek; below Spring Creek (Reach 3); above Clancy (Reach 5); below Lump Gulch (Reach 8); below Montana City (Reach 10); below East Helena (Reach 13); and below the City of Helena sewage treatment plant outfall (Reach 17).

The status of fish populations is the most visible indicator of the biological health of a stream. The fish populations of Prickly Pear Creek should be better quantified, not only to establish resident baseline levels, but also to improve our understanding of the impacts of ammonia, dewatering, and fish barriers (the ASARCO dam and the Wilson Ditch diversion) on the spawning efforts of migratory fish. Without this baseline fishery information, the effectiveness of the specific corrective measures prescribed in this plan could not be properly documented.

<u>General Recommendation 4.</u> Support should be given to research that would quantify the effects of suspended sediment and the fine fraction (sand and gravel) of the bed load, and of heavy metal pollution, on the aquatic environment of Prickly Pear Creek.

While there is sufficient qualitative information to determine the major sources of sediment pollution in the Prickly Pear drainage, no quantitative data exists on the seasonal variability of sediment loads, the particle size and amount of sediment transported, and the yield of sediment from various portions of the drainage.

This information would provide a better understanding of the extent to which suspended sediment concentrations limit the aquatic productivity of various stream reaches. It would also serve as a baseline description of sediment production and yield in the drainage, which could be used to measure progress at reducing sediment loads of the stream or to document additional impacts.

Water chemistry and quality in the drainage have been described in sufficient detail to delineate major problem areas (Montana DHES 1981, Stiller and Associates 1983). However, even in the most thoroughly studied areas (Spring Creek and Prickly Pear Creek below the Helena wastewater treatment plant outfall), the data base is inadequate to define the dissolved and suspended chemical load of the stream over an extended period of time. It is also inadequate to define the frequency and extent of any water quality standard violations.

We suggest stream sampling of sufficient frequency to develop statistically significant relationships between water quality parameters and streamflow variation at critical locations in the drainage. The sampling program should also examine the relationship between pollutants (heavy

metals in particular) and sediments. The stream's sediment geochemistry may play an important role in determining water quality.

This water quality information would provide a more complete basis for defining the effects of pollutants on aquatic life. Baseline information would be particularly valuable for evaluating the success of future efforts to reduce acid mine drainage and heavy metals pollution in the Spring Creek drainage.

SITE-SPECIFIC POLICIES and TREATMENTS.

General problems such as heavy metal or sediment pollution affect Prickly Pear's water quality over much of the stream. In contrast, individual problem sites such as eroding banks, failing riprap, debris jams, and areas with site-specific fisheries problems, may affect only a small segment of stream and its users. Numerous individual site problems contribute to the drainage-wide sediment pollution problem, but some are more important than others.

Initially, each individual problem site requiring corrective work was ranked as "high," "medium," or "low" priority (see Chapter III, page 38). This ranking was done using available information on the site and its setting, with little consideration given to broad-scale concerns or the site's relationships to others in the drainage.

Once the initial inventory and ranking was completed, each site was reviewed in context. Many sites on the initial list were eliminated because they were too small, too isolated, had poor access, or were otherwise of such limited importance that corrective work was not warranted. The tables in Appendix C summarize the following information for each site remaining after the screening process: type of problem; work priority; physical bank features; and recommended corrective treatment. As described in the work plan for site treatments (page 65), some of these sites, including some with "high" priority, are not recommended for immediate work.

The following specific policies and site treatments for the Prickly Pear drainage begin with upstream channel reaches and progress systematically downstream.

Spring Creek Drainage.

Policy Recommendation 1. Strong support should be given to the Montana Department of State Lands in its effort to formulate and fund a reclamation plan for the Corbin-Wickes abandoned mine area. If a gold mine is opened near Corbin and Wickes, the Conservation Districts should urge the state and the mining companies to develop strong controls on heavy metal and sediment pollution reaching Prickly Pear Creek.

The control of pollution by heavy metals in the Corbin-Wickes area will probably be funded by a joint federal-state effort (Office of Surface Mining and Montana Department of State Lands), perhaps along with a private mining company. Planning on this project is well under way but could be accelerated, particularly if the public expresses support for the reclamation program.

The Districts' efforts should include technical review of proposed mine plans, environmental assessments, and construction, operating, and decommissioning specifications. Particular attention should be placed on the adequacy of proposed water pollution abatement measures such as the mine drainage and sediment detention network, as well as on long-term reclamation plans.

A possible component of reclamation, storage of spring runoff in alluvial aquifers in the Wood Chute drainage and near Spring Creek, could increase base flow downstream in Spring Creek. This would enhance the existing fishery in the middle section of Spring Creek (above Corbin), and possibly aid in the design and operation of reclamation, or mitigate the adverse effects of mining operations in the Corbin-Wickes area. Heavy metals concentrations there, and to a much lesser degree in Prickly Pear Creek, would be diluted, perhaps producing a modest improvement of the aquatic environment during low flow months.

Treatment Recommendation 1. If no overall project to rehabilitate the Corbin-Wickes area is under way within three years, the Conservation Districts should strongly support temporary control of bank erosion and related sediment yields to Spring and Corbin creeks.

Fine-grained sediment carried downstream from the Corbin-Wickes area degrades the aquatic environment of Prickly Pear Creek. This sediment problem would likely be greatly reduced or eliminated if the Montana Department of State Lands and the Office of Surface Mining carry out the project to clean up the area.

Intensive efforts to establish bank vegetation, coupled with diking to control sheetwash erosion on bare tailing piles and the use of sediment detention basins to trap sand and silt, could reduce sediment pollution at Corbin-Wickes (although heavy-metal pollution and related problems would not yield to this approach). This sediment-control work would complement parallel work on eroding banks in channel reaches 1 through 5, and the higher-priority work downstream in reaches 6 through 10.

Channel Reaches 1 through 5.

Policy Recommendation 2. Because heavy metals from the Corbin-Wickes area limit the fishery in these reaches, instream enhancement of aquatic habitat or erosion control would do little good. If heavy metal pollution (and, less significantly, sediment pollution) from the Corbin-Wickes area is controlled, enhancement of aquatic habitat and control of erosion of fine-grained sediment would then be worthwhile, and should be given the same high priority as reaches 6 through 10.

Reaches 1, 2, and 3 extend downstream from Jefferson City to just above Dutchman Creek. These three reaches are in the "impact zone" of pollution by heavy metals from the Corbin-Wickes area. Reaches 4 and 5, between Dutchman Creek and the mouth of Warm Springs Creek, are less affected by heavy metals, but do not support a healthy fishery.

All five reaches, degraded by silt and sand from the Spring Creek drainage, have an extensively altered channel that flows through old dredge tailings. Many eroding banks contribute sediment pollution, although few threaten structures. Some of the fine-grained sediment (sand and silt) eroded here is carried to reaches 6 through 11, where there is a better aquatic environment and fishery. The detrimental effect of this sediment is probably less than that of the sediment entering the stream from Clancy Creek and from eroding banks in reaches 6 through 10.

Water quality could improve along reaches 1 through 5 if a mine opens at Corbin-Wickes, or if cleanup of Corbin-Wickes is done by government agencies. In that case, the Conservation Districts' work priorities should shift to these reaches on the mainstem of Prickly Pear. Improving reaches 1 through 5 would nearly double the length of stream with acceptable aquatic habitat. Once the stream has flushed out the worst of polluted bed sediments, it may only take a few years to achieve fair to good aquatic conditions between Jefferson City and Alhambra.

In the event that the heavy metals-acid mine drainage problem is cured, but funding for work on the mainstem of Prickly Pear is limited, highest priority should be given to downstream sites (reaches 4 and 5). In the vicinity of the mouth of Dutchman Creek and Alhambra, Prickly Pear has a marginally-acceptable aquatic condition and fishery. Therefore, this part of the stream would respond more quickly, and with less effort and expense than the upstream reaches in the main "impact zone".

Treatment Recommendation 2. **Control of bank erosion that threatens structures in channel reaches 1-5 should be done based on landowner needs.**

Protecting structures by the recommended techniques also controls bank erosion, reducing sediment levels in the stream channel. In addition, landowners' cooperation is essential for the management plan to succeed; one of their primary concerns is protecting buildings, bridges, and croplands from erosion.

Warm Springs Creek.

Treatment Recommendation 3. **Work on Warm Springs Creek should begin with grazing management and reestablishment of bank vegetation to aid in bank stabilization.**

Warm Springs Creek has a few seriously-eroding banks that deserve attention and several sections that apparently were destabilized during floods in 1975 and 1981 (see figure II-4). These sections have braided channels that could be stabilized with limited earth moving and subsequent revegetation. Banks are broken down in several heavily-grazed sections; fencing or other reduction of grazing pressure would help. Work on this stream should have lower priority than on Clancy Creek.

Clancy Creek.

Treatment Recommendation 4. **Fine-grained sediment erosion along Clancy Creek should be controlled initially by streambank fencing to eliminate grazing near the stream and by planting shrubs and grass.**

Control of fine-grained sediment pollution will improve the aquatic habitat of lower Clancy Creek and Prickly Pear Creek below Clancy, particularly along reaches 6 through 10, which are targeted for high priority work. A detailed

survey of problem areas (shown in figure II-4, page 24) is needed to refine cost estimates and work plans.

Limited structural measures may be needed to control erosion at a few critical areas. However, until floodplain and upper bank vegetation is reestablished and animal traffic on stream banks reduced, further structural improvements would be futile. It would be worthwhile for the Conservation Districts to investigate the possibility of introducing beaver into the problem areas shown on figure II-4. Beaver dams in these areas would initially contribute to the stabilization of the streambed and help reduce the erosive power of the stream.

Channel Reaches 6 through 10.

Treatment Recommendation 5. **Control of erosion of fine-grained sediment and improvement of aquatic habitat, along with parallel work to protect structures, roads, and farmland, should be concentrated between McClellan Creek and Clancy (reaches 6 through 10), with high priority given to downstream reaches if funds are limited.**

In contrast to upstream sections, the reaches between McClellan Creek and Clancy provide the best aquatic habitat on Prickly Pear Creek, with conditions, on the average, improving downstream. An integrated attack on all seriously-eroding banks, coupled with instream habitat enhancement to improve the diversity and quality of the aquatic environment and fishery, would be very effective.

This channel segment, extending from Clancy to just above East Helena, has the highest priority for streambank protection and aquatic habitat improvement efforts. The work should not be contingent on parallel efforts in the Spring and Clancy creek drainages, although it is recommended that the Districts encourage and participate in activities to restore water quality to Spring Creek and reduce sediment loads of both streams.

The section of stream extending from just above East Helena to Clancy has sufficiently good water quality and channel stability to support a modest trout population. Presently the lack of suitable habitat and high loads of fine sediment are limiting overall productivity. Erosion and sediment yield from the Spring and Clancy creek tributaries, as well as along eroding banks on the mainstem, cause the sediment and habitat problems in this stream segment. Table III-1 (page 43) shows the sections of stream in reaches 6 through 10 where work on aquatic environment and fisheries should be concentrated.

Policy Recommendation 3. The Districts should begin plans to develop a Prickly Pear park system.

Several locations along this section of Prickly Pear would make excellent roadside parks, with access for fishing, streamside nature walks, and related recreation. Listed in table C-3 of Appendix C, many of these sites receive heavy usage, but lack of development and maintenance limits the quality of recreation.

McClellan Creek.

The dam just above the mouth of McClellan Creek traps most of the sediment entering the reservoir, preventing it from entering Prickly Pear Creek. Therefore, no restoration or other work is recommended for McClellan Creek.

Channel Reaches 11 and 12.

Treatment Recommendation 6. Bank stabilization to protect structures and other improvements, and to control erosion of fine-grained sediment, should be done based on landowners' needs. Control of erosion by reduction in grazing intensity (through fencing and/or rotational grazing) is recommended in conjunction with the use of flow deflection at critical locations.

The stream in these reaches has good aquatic habitat interspersed with stretches of stream destabilized by slight buildup of coarse sediment (pebbles and gravel) deposited by the 1981 and earlier floods. Eventually the stream will probably move sand and gravel downstream and out of the areas of extensive channel changes. Banks will build up and become vegetated, and a meandering channel pattern will again be achieved. Until this happens, bank stabilization, sediment control, and aquatic habitat improvement should be given low priority relative to reaches 6 through 10.

Cattle grazing has hindered regrowth of shrubs and ground cover on gravel bars, overbank gravel deposits, and eroded banks. Grazing control is particularly important in these reaches, where the stream has the potential to reestablish a natural meandering pattern that would resist future floods and provide better bottom land cover for cattle and wildlife, as well as fish habitat.

Policy Recommendation 4. The Conservation Districts should establish a committee, including representatives of ASARCO, other landowners, citizens groups, and tech-

nical advisors, to plan restoration where the creek passes the ASARCO slag dump.

Construction of levees, riprapped banks, channelized reaches, or other extensive structural modification is not recommended for reaches 11 and 12, except in the section of channel between the ASARCO dam and Highway 12 in East Helena. In the vicinity of ASARCO's slag pile, structural controls (for example a low retaining wall) will be necessary to isolate the stream from this sediment source. This riparian area of Prickly Pear has considerable need for control of slag erosion, aesthetic improvements near Highway 12, and enhancement of the aquatic environment and fishery.

Channel Reaches 13 and 14.

Policy Recommendation 5. Efforts to correct the dewatering problem should take a slightly higher priority than correcting the ammonia problem, in the short-term. In the long-term, both deserve high priority.

Below East Helena (reaches 13-18), the aquatic environment and fishery are severely degraded by dewatering and ammonia pollution. In the Helena Valley, greater benefit to the stream system--including the physical (hydrological) and biological environment, and land use of the riparian zone--would be gained from correcting the dewatering problem than from correcting the ammonia problem. The former affects not only the fishery and related instream aquatic values, but also the physical (hydrological) environment and land use in and near the stream. The latter primarily affects the fishery and aquatic values, and only secondarily the other values.

The ammonia contamination in the lower drainage discourages successful upstream migration of trout during the fall spawning season. But, without correction of the heavy metal pollution, much of the stream above Clancy is not usable by trout, and populations in the vicinity of the dewatered reach lower on the stream are decimated nearly every year.

Policy Recommendation 6. The Conservation Districts should assist in the development and support the passage of legislation allowing the transfer of water rights for instream flow purposes. Once this critical step is accomplished, the Districts should further evaluate the feasibility of solving the dewatering problem below East Helena.

The use of ground water to sprinkler-irrigate fields is probably the least expensive means of lessening or eliminating dewatering in Prickly Pear Creek below East Helena. Water now withdrawn by irrigators from Prickly Pear could remain in the channel. A minimum of about 800 miners inches (20 cfs) presently allotted for surface irrigation would need to be converted to an instream use to provide for maintenance of aquatic habitat.

In addition to legal obstacles, the availability of ground water for irrigation could limit the feasibility of this approach. A detailed analysis of the valley's ground water system is necessary to determine if sufficient water is available to meet the potential irrigation demand.

Treatment Recommendation 7. **Areas of bank breakdown by cattle should be fenced, or grazing pressure reduced. Protection of structures and cropland should be done based on landowners' needs.**

Channel Reach 14, which includes the stream segment adjacent to the Helena Sand and Gravel operation, is in obvious need of bank stabilization and revegetation. However, until the dewatering problem is corrected, there is little need for instream work to improve the aquatic environment or for control of bank erosion, except where structures or important cropland are threatened.

Land lost to the stream at an eroding bank (except in certain special cases) is replaced by deposition of sediment on the other bank. The slow buildup of rich overbank sediment occurs as a stream erodes laterally and migrates slowly across its floodplain. Attempts to completely stop this process on floodplains may lead to destabilization of the stream and excessive costs for channel maintenance.

Channel Reaches 15, 16, 17, and 18.

Policy Recommendation 7. **The Conservation Districts should urge the City of Helena and the Montana DHES to investigate the practicality of various ammonia control methods, especially pH control with break-point chlorination and rapid infiltration. Alternate points of discharge such as Lake Helena should be investigated. The costs and benefits of upgrading the stream's water quality classification from E should be evaluated.**

Ammonia and related pollutants enter the stream from the discharge of the City of Helena's wastewater treatment plant. Excess ammonia could be prevented from entering the stream by expanding the plant, constructing a rapid-infil-

tration drain field, or diverting the ammonia-bearing discharge away from the stream, by a ditch or pipe.

As noted earlier, most plant expansions for ammonia removal would be extremely expensive. The least expensive would probably be pH control to increase acidity, coupled with break-point chlorination. Other in-plant solutions would be extremely costly to construct and operate. A rapid-infiltration installation would cost from two to seven million dollars, depending on aquisition costs for land, and specific design considerations.

The current water quality classification of the stream north of East Helena is E (suitable for agricultural and industrial use), the lowest possible. A long term management goal should be to upgrade that classification, recognizing the benefits that society would reap from improved water quality. The City of Helena and the Water Quality Bureau, at the urging of the Conservation Districts, should seriously examine these benefits as well as the associated costs.

Treatment Recommendation 8. **The Conservation Districts should instigate a systematic fencing and grazing management program for heavily-grazed stream banks in the Helena Valley.**

The stream in these reaches, principally north of Canyon Ferry Road in the Helena Valley, is mostly meandering, but has a few almost straight, braided sections, some of which are natural, some of which are channelized. At several sites, structures, such as irrigation diversions, power poles, and fences, are threatened. Control of bank erosion will not be needed, except for protection of structures or important cropland, until the ammonia pollution is reduced.

Along many sections of the stream, heavy grazing has removed bank vegetation and broken down banks. Grazing reduction, by streambank fencing in most places, would allow banks to recover and stabilize. Of the 12 miles of channel below East Helena, about 50 per cent would benefit from fencing. Assuming a 10-foot set-back on both banks, roughly 14.5 acres of land would be excluded from grazing if all the recommended fencing were installed.

ALTERNATIVE WORK PLANS for SITE TREATMENT

Reducing or eliminating the heavy metal pollution and acid mine drainage in Prickly Pear's upper reaches is beyond the Conservation Districts' ability, as is solving the ammonia pollution problem and perhaps the dewatering problem in the stream's lower sections.

This suggests that the best management strategy is to deal with erosion and sedimentation, particularly in reaches 6 through 10, where the fishery is least affected by chemical pollution. Areas where bank erosion threatens houses, bridges, cropland, and other land uses also have a high priority for protection.

Developing the cost estimates first entailed measuring the quantities of treatments, ranging from riprap to revegetation, then estimating the unit costs of the various treatments. Unit costs (summarized in Appendix C) were estimated by reviewing bids for similar work recently let by the Montana Department of Highways and adjusting them to account for different quantities and sources of materials. These costs are considered reliable, because construction costs have stabilized in recent months, and conservative, because there may be more economical ways to accomplish the same results than by advertising for bids on a single, large project. For example, the Conservation Districts may enter joint ventures with riparian landowners or others who have equipment of labor to contribute.

Recognizing potential funding limitations, Streamworks has developed three work plan alternatives. Each would protect structures, reduce sediment pollution, and improve riparian and aquatic habitat. In doing so, streamside aesthetics would also improve. The preliminary cost estimates used to develop the alternatives are provided in Appendix D, tables D-1 to D-3.

Reach-by-reach costs are given for channel rehabilitation of the entire drainage, except for: Spring Creek (table D-1); bank protection at only those sites where erosion threatens structures (table D-2); and recommended streambank fencing (table D-3). These latter costs are included in the drainage-wide estimates given in table D-1.

Alternative A, at a cost of $639,500, is the most expensive of the three options. However, it is $300,000 less than the amount estimated for rehabilitation of the entire drainage (see Appendix C). This one-third reduction is based on the futility of carrying out many channel stabilization measures in the stream's upper and lower reaches until the ammonia, dewatering, and heavy metal problems are solved. Although sediment contributes significantly to poor water quality in the entire drainage, aquatic

TABLE IV-1.

Channel Rehabilitation Alternative A*

Channel improvements to protect structures and reduce sediment pollution.	$150,200
Mainstem streambank fencing above East Helena (11,400 lineal feet).	14,300
Mainstem streambank fencing below East Helena (62,250 l.f.)	77,800
Clancy Creek streambank fencing and revegetation.	78,500
Warm Springs Creek streambank fencing and revegetation.	27,300
Channel reaches 6-10:	
Improvements to reduce sediment pollution and improve riparian and aquatic habitat.	121,000
Fish habitat improvement demonstration projects.	17,000
Channel Reach 11--reduction of sediment pollution (Kleffner's and vicinity).	30,300
Channel Reach 12--reduction of sediment pollution (ASARCO and East Helena.	62,600
Channel Reach 14--reduction of sediment pollution (Burnham's and gravel pits).	60,500
	$639,500

*Alternative includes 100% of recommended work for each item.

TABLE IV-2.

Channel Rehabilitation Alternative B.

75% of channel improvements to protect structures and reduce sediment pollution.	$112,700
50% of mainstem streambank fencing above East Helena (5,700 l.f.).	7,200
50% of mainstem streambank fencing below East Helena (31,125 l.f.).	38,900
80% of Clancy Creek streambank fencing and revegetation.	62,800
80% of Warm Springs Creek streambank fencing and revegetation.	21,800
Channel reaches 6-10:	
80% of channel improvements to reduce sediment pollution and improve riparian and aquatic habitat.	96,800
Fish habitat improvement demonstration projects.	17,000
Channel Reach 11: 80% of channel improvements to reduce sediment pollution.	24,200
Channel Reach 12: 80% of channel improvements to reduce sediment pollution.	50,100
Channel Reach 14: 80% of channel improvements to reduce sediment pollution.	48,400
	$479,900

TABLE IV-3.

Channel Rehabilitation Alternative C.

50% of channel improvements to protect structures and reduce sediment pollution.	$75,100
50% of mainstem streambank fencing above East Helena (5,700 l.f.).	7,200
20% of mainstem streambank fencing below East Helena (12,450 l.f.).	15,600
50% of Clancy Creek streambank fencing and revegetation.	39,300
None of Warm Springs Creek streambank fencing and revegetation.	
Channel reaches 6-10:	
60% of channel improvements to reduce sediment pollution and improve riparian and aquatic habitat.	72,600
Fish habitat improvement demonstation projects.	17,000
Channel Reach 11: 20% of channel improvements to reduce sediment pollution.	6,100
Channel Reach 12: 50% of channel improvements to reduce sediment pollution.	31,300
Channel Reach 14: 25% of channel improvements to reduce sediment pollution.	15,100
	$279,300

habitat and the trout fishery cannot be significantly improved as long as these other barriers exist.

Alternative A therefore emphasizes making improvements where they will do the most good (see table IV-1). Alternatives B and C are grounded in the same logic, but reflect lower funding levels--$479,900 for B and $279,300 for C (tables IV-2 and IV-3). The less-costly options are directed to the higher-priority sites and reaches.

Alternative C represents a good starting point for rehabilitating Prickly Pear Creek. Although not addressing all of the erosion and sedimentation problems in the drainage, it would serve as a valuable demonstration of the potential for Prickly Pear to become a healthy stream. Landowners and the public would be able to see the effects of recommended measures on a limited scale, motivating interest in widespread application of the successful techniques. Alternative B would address the same high-priority items, only on a greater scale, and with more drainage-wide benefits.

Successful accomplishment of Alternative A, B, or C depends on both landowner cooperation and the availability of funding of the work. Potential funding sources are described in Chapter V.

Although it was beyond the scope of this investigation to talk with every landowner in the drainage, those contacted were generally receptive to the proposed channel modifications. Relations between the Districts and the landowners in the watershed are good; nonetheless, considerable ongoing landowner-District coordination will be necessary to accomplish the site-specific channel work and to ensure that the general streambank management recommendations are carried out.

Management of streambank grazing will require the Districts to review and determine the specific needs of each interested landowner. Once this is done, the Districts could provide sufficient funding for streambank fencing from a general fund or assist landowners in obtaining matching funds. Various riparian management programs could reduce the cost of fencing and construction of cattle access to water by 50 per cent if the landowner does the work. Because effective management of streambank grazing includes the monitoring of revegetation success, fence maintenance, and other performance evaluations, the Districts should provide this assistance on a continuing basis.

Channel improvement work requiring structural modification of streambanks can be done several ways. First, at an individual problem site (or preferably over a channel reach), a final design and work specifications should be prepared. Work specifications include drawings showing the

locations of structures, specific vegetation plantings, and quantities of earth work. Additional final design details include various hydraulic analyses such as sizing of riprap or materials in jetties and determination of the placement of boulders for habitat enhancement. The cost estimates given for alternatives A, B, and C are preliminary and include a 25 per cent allowance for final engineering design, cost estimation, and contingencies.

Once the final design is prepared, the Districts could either let contracts through competitive bidding or provide guidance and assistance to landowners who have the skills and equipment to perform the work.

Some of the recommended channel work falls outside areas that directly affect landowners. To make channel improvements in an efficient, coordinated manner, it may be necessary to group various reaches (6-10, for example) together and treat them as an overall channel improvement project. After funding is obtained, final design and specifications for the work would be prepared and contracts let to perform the entire package of work.

The execution of Alternative A, B, or C will probably involve significant administrative participation by the Conservation Districts, the Soil Conservation Service, the Montana Department of Health and Environmental Sciences, the Montana Department of Natural Resources and Conservation, and the Montana Department of Fish, Wildlife and Parks. If sufficient staff are not available, an additional allowance for hiring a short-term program coordinator could be made. Duties could include fund-raising, coordinating with landowners and government agencies, contracting, and construction supervision.

CHAPTER V

FUNDING FOR PRICKLY PEAR CREEK IMPROVEMENTS

Solving erosion and sedimentation problems in the Prickly Pear drainage is well within the realm of accomplishment by the Conservation Districts. The Districts should immediately seek funding for bank stabilization, revegetation, fisheries enhancement, and grazing management. Many of the funding sources presented here are well-suited to this task.

At present it is premature for the Districts to seek funding to correct any of the other problems identified. State and federal plans and funding are likely to be forthcoming for reclamation work in the Spring Creek drainage. The ammonia problem in lower Prickly Pear Creek will be costly to solve and will require testing of various methods. The City of Helena should take the lead in securing funding for needed studies. Any method for rewatering Prickly Pear Creek downstream from East Helena will require overcoming legal obstacles to the transfer of water rights to a public agency for instream flow.

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION.

Conservation Districts Division.

The Conservation Districts Division of DNRC administers "223 Funds" which are available to conservation districts. These funds were appropriated from coal tax revenues by the 1981 Legislature. Conservation districts may use the funds for any conservation purpose authorized under their enabling act, except for administration.

The Division receives approximately $50,000 per quarter from coal severance tax revenues. The Resource Conservation Advisory Council reviews applications each quarter and selects projects to be funded. Projects which serve a public need or purpose, or which can be completed with lower levels of funding, receive a higher rating. The Division recommends that applications not exceed $20,000. The Council will often approve partial funding for an application, and a district can reapply in subsequent quarters for the unfunded amount. To qualify for "223 Funds", a conservation district must be assessing and using the one and a half mills authorized under the enabling statute.

Water Development Bureau.

DNRC's Water Development Bureau administers two programs also funded from coal severance tax revenues. Both programs, the Water Development Program and the Renewable Resources Development Program, provide grants and loans for planning or construction activities. Eligible activities which would benefit Prickly Pear Creek include bank stabilization, fish habitat improvement, rewatering, and erosion control.

Once an application is made, (for either program), DNRC determines which of the two is most appropriate. The application period will begin in February and end May 31, 1984. The Department publishes a brochure and application forms for this program.

The Bureau screens each application to determine whether a project is technically and economically feasible, and then ranks the candidates. The priority recommendations are sent to the Governor, who submits recommendations to the Legislature. The 1985 Legislature will make the final decision on awarding grants or loans. Because these two programs are intended to address the kinds of problems affecting Prickly Pear Creek, a favorable review is likely.

State legislation allows public agencies to issue bonds backed by coal tax revenues. Information on coal tax bonding is available from the Water Development Bureau.

MONTANA DEPARTMENT of FISH, WILDLIFE and PARKS.

The Fisheries Division of the Department of Fish, Wildlife and Parks (DFWP), along with the Conservation Districts Division of the Montana Department of Natural Resources and Conservation, administers the Streambank Preservation Program. The program, funded from coal severance tax revenues, includes streambank stabilization and structural habitat improvement as eligible activities.

The program is limited to $5,000 per land occupier, with $45,000 available for fiscal year 1984. A dollar-for-dollar match, in either funds of in-kind services, is needed to receive funding under this program.

An application to the Department should specify in detail the proposed work, appropriate photos, drawings and explanation.

MONTANA DEPARTMENT of STATE LANDS.

The Montana Department of State Lands (DSL) has funds available under the Metal Mine Reclamation Act (Title 82, Chapter 4, Part 3) for "research, reclamation and revegetation of land and rehabilitation of water affected by any mining operations." It may be possible to obtain funds for certain facets of rehabilitation work on Prickly Pear Creek by submitting an unsolicited proposal to DSL.

Currently, the DSL has approximately $35,000 which has been collected from fines, fees and penalties assessed under "Section 82-4-311, MCA, Hard-rock Mining Account." This section of Montana law states:

> 82-4-311. Hard-rock mining account. All fees, fines, penalties, and other uncleared moneys which have been or will be paid to the department of state lands under the provisions of this part shall be placed in the earmarked revenue fund in the state treasury and credited to a special account to be designated as the hard-rock mining and reclamation account. This account shall be available to the department by appropriation and shall be expended for the research, reclamation, and revegetation of land and the rehabilitation of water affected by any mining operation. Any unencumbered and any unexpended balance of this account remaining at the end of a fiscal year shall not lapse but shall be carried forward for the purposes of this section until expended or until appropriated by subsequent legislative action.

AMERICAN SMELTING and REFINING COMPANY (ASARCO).

The manager of ASARCO's East Helena Plant supports the stabilization of Prickly Pear Creek streambanks that are affected by ASARCO's operations. He also is interested in improving the visual appearance of ASARCO property east of the creek. He has reservations about constructing a public recreation area because of the long term problems of maintenance and the possible conflict between high recreation use and nearby residents. He realizes that stabilizing the streambanks below the ASARCO dam will have long-range benefits to the company as well as improving water quality and the fisheries resource.

The manager would like to have several ASARCO representatives serve on a committee to develop final plans for stream protection and improvements on the grounds east of the stream. He feels that one or two representatives of the residential area adjacent to the creek should represented.

The Conservation Districts, or the now inactive Prickly Pear Creek Task Force, could take the lead in setting up a planning group for that area. The planning group should be comprised of several interests and organizations--ASARCO, the Lewis and Clark Conservation District, the Department of Health and Environmental Sciences, the Department of Fish, Wildlife and Parks, the Prickly Pear Sportsmen's Association, and the City of East Helena.

NATIONAL ENDOWMENT for SOIL and WATER CONSERVATION.

The National Endowment for Soil and Water Conservation is a private, nonprofit organization formed to raise tax-exempt monies from the private sector to carry out conservation work. The Endowment will locate financial support for selected soil and water conservation projects in three main categories: incentive programs, applied research, and education. The Endowment acts as a clearinghouse to find funding for inexpensive but effective conservation projects.

When a conservation district requests funding for a project, the Endowment adds the project to its catalog and then searches for funding from private companies and foundations. Projects costing between approximately $3,000 to $10,000 are eligible. The Endowment provides a two-page application form for requesting assistance on a project.

MONTANA DEPARTMENT of HEALTH and ENVIRONMENTAL SCIENCES

The Water Quality Bureau of the Montana Department of Health and Environmental Sciences administers EPA 205(J) funds, which are available for planning, monitoring, and studying water quality issues on high-priority problem stream segments (the current Prickly Pear study is funded from this program).

The funds cannot be used for construction or enforcement, but are an appropriate source of funding for any additional or follow-up monitoring on Prickly Pear or its tributaries.

OTHER POSSIBLE SOURCES of ASSISTANCE.

Civic Organizations.

Voluntary labor for activities such as riparian plantings may be available from organizations such as Scouts or 4-H. A club or troop must be approached to assist with a specific project. Several Scout or 4-H leaders have expressed general interest. Organizations such as the Prickly Pear Sportsmen's Association may be able to provide labor on specific projects.

Montana Department of Highways.

Highway 518 from East Helena south to Jefferson City, part of the Federal Aid Secondary System (FAS), is the maintenance responsibility of Jefferson and Lewis and Clark counties. Each county receives funds annually to build or upgrade its FAS highways and must set funding priorities among them. The Montana Department of Highways sees that the funds are expended for eligible activities.

The Department itself maintains the interstate highway system. As a general policy, the Department does not pay for or conduct stabilization work on highway facilities unless a roadway is threatened by erosion, mass-wasting, or other stream-related actions. The Department will not provide funding or work where sedimentation is the only problem.

The Department could, however, do riprapping, revegetation, and other stabilization work along I-15, or approve funding for stabilization work on FAS 518, in areas where Prickly Pear Creek is a threat to safety or the integrity of the highway.

The Conservation Districts should write the Director of the Department, requesting assistance in stabilization work. The letter should emphasize the joint assistance provided by other agencies or firms. The Districts should also write to the county commissioners, requesting that Highway 518 be given a high priority for use of FAS funds and that Jefferson County provide some work and materials.

Burlington Northern Company.

The Burlington Northern Company (BN) currently is removing ties and track from its line south of Montana City, with completion expected this spring. The right-of-way will then be declared surplus and transferred to BN's Property Management Division, which will prepare a sale of the right-of-way segments.

The right-of-way in the Clancy area (the segments of highest interest in our study) are of particular interest. Jefferson County, the State of Montana, and three or four private landowners have indicated interest in buying right-of-way in this area. The Conservation Districts may be able to work with the new owners, public or private, to improve the aquatic environment of and public access to the stream.

Any application to acquire segments of right-of-way should be made as soon as possible. An application consists of a letter expressing interest, accompanied by photos, sketches or other documentation specifying the planned use of the right-of-way.

LITERATURE CITED

American Society of Civil Engineers. Task Committee on Preparation of Sedimentation Manual. 1972. Sediment control methods: B. Stream channels. Journal of the Hydraulics Division 98(HY7):1295-1326.

Anderson, A.G. 1970. Tentative design procedure of riprap lined channels. St. Anthony Falls Hydraulic Lab. Project Report 96. Minneapolis, MN.

Andrews, E.D. 1980. Effective and bankfull discharges in the Yampa River basin, Colorado and Wyoming. Journal of Hydrology 46:311-330.

________. 1981. Measurement and computation of bed-material discharge in a shallow sand-bed stream, Muddy Creek, Wyoming. Water Resources Research 17(1):131-141.

________. 1983. Entrainment of gravel from naturally sorted riverbed material. Geological Society of America Bulletin 94:1225-1231.

________. In press. Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. Geological Society of America Bulletin.

Armour, C.L. 1977. Effects of deteriorated range streams on trout. U.S. Bureau of Land Management. Idaho State Office. Boise, ID.

Barton, J.R. and P.V. Winger. 1973. A study of the channelization of the Weber River, Summit County, Utah. Utah Division of Wildlife Resources and Utah State Department of Highways.

Benson, M.A. and T. Dalrymple. 1967. General field and office procedures for indirect discharge measurements. Techniques of water-resource investigations. In: Applications of Hydraulics. Book 3. U.S. Geological Survey.

Bishop, C. G. 1962. Stream channel alterations inventory, Prickly Pear Creek and Boulder River. Montana Department of Fish and Game. Helena, MT.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. Journal of Wildlife Management 18:229-239.

Bray, D.I. 1982. Regime equations for gravel-bed rivers. In: Gravel bed rivers--fluvial processes, engineering

and management. R.D. Hey, J.C. Bathurst, and C.R. Thorne, eds. New York: John Wiley and Sons.

California Division of Highways. 1970. Bank and shore protection in California highway practice. Department of Public Works. Sacramento, CA.

Carson, M.A. and M.J. Kirkby. 1972. Hillslope form and process. Cambridge: Cambridge University Press.

Charlton, F.G. 1982. River stabilization and training in gravel-bed rivers. In: Gravel bed rivers--fluvial processes, engineering and management. R.D. Hey, J.C. Bathurst, and C.R. Thorne, eds. New York: John Wiley and Sons.

Chow, V.T. 1959. Open-channel hydraulics. New York: McGraw-Hill.

Croley, T.E. 1977. Hydrologic and hydraulic computations on small programmable calculators. Iowa Institute of Hydraulic Research. University of Iowa. Iowa City, IA.

Dunne, T. and L.B. Leopold. 1978. Water in environmental planning. San Francisco: W.H. Freeman and Co.

Environmental Research Technology/Ecology Consultants, Inc. 1979. Revegetation guidelines for the Northern Tier Pipeline Montana segment. Unpublished manuscript pre pared for the Northern Tier Pipeline Company. Fort Collins, Colorado.

Frank Woodnik and Associates. 1983. Personal communication to Joe C. Elliott, Ecological Consultant. Helena. Montana.

Gilbert, G.K. 1914. The transportation of debris by running water. U.S. Geological Survey Professional Paper 86.

Graham, P. 1983. Fisheries biologist, Montana Department of Fish, Wildlife, and Parks. Personal communication to Joe C. Elliott, Ecological Consultant. Helena, Montana.

Gray, D.H. and A. Leiser. 1982. Biotechnical slope protection and erosion control. New York: Van Nostrand Reinhold Company.

Hall, J.D. and C.O. Baker. 1982. Influence of forest and rangeland management on anadromous fish habitat in western North America. Rehabilitating and enhancing stream habitat: 1. Review and evaluation. U.S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. General

Technical Report PNW-138.

Hayes, F. 1978. Streambank stability and meadow condition in relation to livestock grazing in mountain meadows of central Idaho. M.S. Thesis. University of Idaho. Moscow, ID.

Hill, K., and T. Greason. 1981. Unpublished field data. Montana Department of Fish, Wildlife, and Parks. Helena, Montana.

Holton, G. 1983. Assistant Administrator, Fisheries Division, Montana Department of Fish, Wildlife and Parks. Personal communication.

Hunt, W.A. and R.J. Graham. 1972. Preliminary evaluation of channel changes designed to restore fish habitat. Montana Department of Highways, Planning and Research Bureau, and Montana Department of Fish and Game, Environment Bureau. Helena, MT.

Husby, P., and G. Moore. 1982. Riparian vegetation survey of Prickley Pear Creek. Unpublished report submitted to the Lewis and Clark County Conservation District by OEA Research. Helena, Montana.

Hydrometrics, Inc. 1983. Assessment of availability of groundwater for municipal water supply--Helena, Montana. City of Helena. Helena, MT.

Klingeman, P.C. and J.B. Bradley. 1976. Willamette River basin streambank stabilization by natural means. U.S. Army Corps of Engineers, Portland District, and Water Resources Research Institute, Oregon State University. Corvallis, OR.

Knudson, K. 1981. Unpublished field data. Montana Department of Fish, Wildlife, and Parks. Helena, Montana.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. San Francisco: W.H. Freeman & Co.

Limerinos, J.T. 1970. Determination of the Manning coefficient from measured bed roughness in natural channels. U.S. Geological Survey Water Supply Paper 1898-B.

Lines, I.L., Jr., J.R. Carlson, and R.A. Corthell. 1978. Repairing flood-damaged streams in the Pacific Northwest. Presented at the National Riparian Ecosystems Symposium, Callaway Gardens, Georgia. Dec. 11-13, 1978.

Long, S. 1981. Characteristics of plants used in western reclamation. 2nd ed. Environmental Research and

Technology Inc. Fort Collins, Colo.

Lusby, G., V.H. Reid, and O.D. Knipe. 1971. Effects of grazing on the hydrology and biology of the Badger Wash basin in western Colorado, 1953-66. U.S. Geological Survey Water Supply Paper 1532-D.

Marcuson, P.E. 1977. The effect of cattle grazing on brown trout in Rock Creek, Montana. Montana Department of Fish, Wildlife and Parks. Project No. F-20 R-21-11-a. Helena, MT.

Menke, J., ed. 1978. A symposium on livestock interactions with wildlife, fisheries and their environments--Sparks, Nevada. May, 1977. U.S. Department of Agriculture. Forest Service. Pacific Southwest Forest and Range Experiment Station. Berkely, CA.

Montana Department of Health and Environmental Sciences. 1981. Prickly Pear Creek. A report on man's debilita ting impacts. Helena, MT.

Montana Department of Natural Resources and Conservation. 1974. Draft environmental impact statement--Prickly Pear Creek water diversion proposal. Water Resources Division. Montana DNRC. Helena, MT.

Morrison-Maierle, Inc. 1983. Draft flood insurance study--Lewis and Clark County, Montana. Federal Emergency Management Agency. Federal Insurance Administration. Project No. 1535-04-04(33).

Newton, J. 1981. A stream on the mend. Oregon Wildlife. February: 3-6.

Parrett, C., R.J. Omang, and J.A. Hull. 1982. Floods of May 1981 in west-central Montana. Water Resources Investigation 82-33. U.S. Geological Survey. Helena, MT.

________. 1983. Mean annual runoff and peak flow estimates based on channel geometry of streams in northeastern and western Montana. Water Resources Investigation 83-4046. U.S. Geological Survey. Helena, MT.

Platts, W.S. 1978. Livestock interactions with fish and aquatic environments: Problems in evaluation. Transactions of the 43rd North American Wildlife and Natural Resource Conference. Wildlife Management Institute. Washington, DC.

________. 1979. Proceedings of the forum: Grazing and riparian/stream ecosystem. Denver, CO. Nov. 3-4, 1978. Trout Unlimited.

Reeves, G.H. and T.D. Roelofs. 1982. Influence of forest and rangeland management on anadromous fish habitat in western North America. Rehabilitating and enhancing stream habitat: 2. Field applications. U.S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-140.

Riestenberg, M. and S. Sovaoick-Dunford. 1983. The role of woody vegetation in stabilizing slopes in the Cincinnati area, Ohio. Geological Society of America Bulletin 94:506-518.

Rudio, R. 1983. Preliminary feasibility study of removal of Alta Mine Dump and Bertha Mine Dump Reclamation Plan. Unpublished report. Rudio and Associates. Clancy, Montana.

Shields, R.R. and M.K. White. 1981. Streamflow characteristics of the Hudson Bay and upper Missouri River basins, Montana, through 1979. U.S. Geological Survey. Water Resources Investigation 81-32. Helena, MT.

Schofield, R. 1984. Helena Valley Irrigation Supervisor. Personal communication to Chuck Dalby, Streamworks, Helena, MT.

Schumm, S.W. 1969. River metamorphosis. Journal of the Hydraulics Division. American Society of Civil Engineers 95(HY1):255-273.

________. 1977. The fluvial system. New York: John Wiley and Sons.

Shen, H.W. 1979. Modeling of rivers. New York: John Wiley and Sons.

Shetter, D.S., O.H. Clark and A.S. Hazzard. 1949. The effects of deflectors in a section of a Michigan trout stream. Transactions American Fisheries Society 76:248-278.

Simons, D.B. and R.M. Li. 1982. Bank erosion on regulated rivers. In: Gravel bed rivers--fluvial processes, engineering and management. R.D. Hey, J.C. Bathurst, and C.R. Thorne, eds. New York: John Wiley and Sons.

Sindelar, B. 1973. Dryland sodding with native grasses for permanent erosion control. Montana Agricultural Experiment Station Research Report 43. Montana State University. Bozeman, Montana.

Steucke, W. 1982. Letter from W. Steucke, U.S. Fish and Wildlife Service, Billings, MT, to Richard Gorton, Omaha District Corps of Engineers.

Stiller and Associates. 1983. Prickly Pear Creek abandoned mined lands study. Consultant report for Montana Department of State Lands. Helena, MT.

Stipo, V. 1979. Finding of no significant impact--Streambank Erosion Control Project--lower Yellowstone River, ND and MT. U.S. Army Corps of Engineers.

Thomas, W.A. 1977. Sediment transport. Hydrologic engineering methods for water resources development, Volume 12. Hydrologic Engineering Center. U.S. Army Corps of Engineers. Davis, CA.

Thorne, C.R. 1978. Processes of bank erosion in river channels. PhD. Thesis. University of East Anglia. Norwich, United Kingdom.

________. 1982. Processes and mechanisms of river bank erosion. In: Gravel bed rivers--fluvial processes, engineering and management. R.D. Hey, J.C. Bathurst, and C.R. Thorne, eds. New York: John Wiley and Sons.

Thurston, R.V., R.C. Russo, and K. Emerson. 1974. Aqueous ammonia equilibrium calculations. Montana State University Fisheries Bioassay Laboratory Technical Report No. 74-1. Bozeman, MT.

U.S. Army Corps of Engineers. 1981. Literature survey and preliminary evaluation of streambank protection methods. Technical Report H-77-9, May, 1977. Appendix A. Final Report to Congress under the Streambank Erosion Control Evaluation and Demonstration Act of 1974. Dec., 1981.

U.S. Bureau of Reclamation. 1958. Hydraulic design of stilling basins and energy dissipators. Technical Information Branch. Engineering Monograph No. 25. Denver, CO.

U.S. Department of Agriculture, Soil Conservation Service. 1976a. Critical area plantings. Montana.

________. 1976b. Streambank protection (vegetative phase). Technical Guide. Section IV. PRC 580-B.

________. 1978. Streams and rivers--Stream management system--Resource use and management system. Soil Conservation Service Technical Guide. Section III-3. December.

________. 1979. Grassed waterway or outlet. 412-1. Montana.

U.S. Department of Interior. Federal Pollution Control Administration. 1968. Water quality criteria.

Washington, D.C.

U.S. Department of Transportation. Federal Highway Administration. 1979. Restoration of fish habitat in relocated streams. Report No. FHWA-IP-79-3. Washington, DC.

U.S. Environmental Protection Agency. 1976. Quality criteria for water. EPA 440/9-76-023. Washington, D.C.

________. 1980a. Ambient water quality criteria. Washington. D.C.

________. 1980b. Innovative and alternative technology assessment manual. Washington, D.C.

________. 1982. Investigation of methods for site specific water quality assessment; Prickly Pear Creek, Montana. Las Vegas, Nev.

U.S. Geological Survey. 1981. Water resources data for Montana. U.S. Geological Survey Water Data Report MT-81-1. Helena, MT.

________. 1982. Water resources data for Montana. U.S. Geological Survey Water Data Report MT-82-1. Helena, MT.

White, R.J. and O.M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Wisconsin Department of Natural Resources, Division of Conservation. Technical Bulletin Number 39. Madison, WI.

Winters, G.R. and J.L. Gidley. 1981. Evaluation of stream channel relocation impacts and mitigation measures on aquatic biota. California Department of Transportation. Report No. FHWA/CA/TL-81-01. Sacramento, CA.

Wolman, M.G. and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68:54-74.

Workman, D.L. 1974. Final report--Evaluation of stream improvements on Prickly Pear Creek. Unpublished report. Montana Department of Fish and Game and Montana Highway Commission. Helena. Montana.

APPENDIX A.

METHODS FOR STABILIZATION OF BANKS AND CHANNELS

Bank Erosion Processes.

The flow of water exerts a shearing force on stream channel bed and banks. Generally, in gravel-bed rivers the bed and bank materials are significantly entrained only at flows approaching bankfull (during floods). During the remaining 90 to 95 per cent of the year, there is little or no erosion. The rate and magnitude of bank erosion at a site are governed by the size distribution and physical properties of the bank material, bank angle, extent and type of vegetation cover, stratigraphy of the bank, and shear stresses.

Fluvial entrainment is responsible for the two main mechanisms of bank retreat. First, the stream flow may remove sediment by direct entrainment from the bank. Second, the flow may scour the base of the bank, resulting in oversteepening and mass failure.

Physical and chemical weathering, excessive moisture (positive pore water pressure), ice abrasion, and heavy traffic by large animals may contribute to the availability of bank materials for subsequent fluvial entrainment and removal. For instance, on steep banks unprotected by vegetation, surface erosion (sheet erosion, rilling, and gulleying) may be several times greater than on vegetated slopes, and significant bank erosion may occur over and above that caused by fluvial entrainment.

Carson and Kirkby's (1972) concept of "basal endpoint control" in the evolution of hillslopes has been applied to the case of river bank erosion by Thorne (1982). It provides a useful conceptual framework for understanding bank erosion processes. Mechanical failure (mass movement) and surface erosion supply material to the toe of the bank (basal area). Removal of this material depends on fluvial entrainment and downstream transport. Where flow is able to remove the material, exposing and scouring the basal area, further bank failure occurs. If flow is unable to remove the debris, basal accumulation occurs, forming a wedge of failed material. That protects the bank from erosion.

Thorne (1978) recognized three states of basal endpoint control:

> Impeded Removal. Bank failures and surface erosion supply material to the base at a higher rate than it can be removed. Basal accumulation results, decreasing

the bank angle and height. The rate of supply decreases in transition to the second state, unimpeded removal.

Unimpeded Removal. Delivery and removal of basal area material are in balance. The bank recedes by parallel retreat at a rate governed by fluvial activity at the base.

Excess Basal Capacity. Basal scour has excess capacity over the supply of material by erosion and bank failure. Bank angle and height are increased as basal lowering occurs. The rate of material supply increases, in transition to the state of unimpeded removal.

At the outer banks of meander bends, downwelling of flow promotes basal scour and entrainment, maintaining the bank in a state of unimpeded removal for long periods.

During floods excess basal capacity dominates. Inflection points (flow cross-overs between meanders) may have conditions of impeded removal for long periods because much larger floods are required for basal scour (Thorne 1982).

In more cohesive bank materials, blocks of root-bound material may accumulate along the basal area, providing natural bank protection and allowing recovery of bank vegetation and transition to a state of impeded or unimpeded removal.

Methods for Protecting Stream Banks against Fluvial Entrainment.

Bank armoring, flow retardation, and flow deflection provide protection against fluvial entrainment. Revetments are the most versatile of the bank armor methods, nearly always preventing erosion caused by abrasion and scour. Structures to retard flow (check dams, drop structures) dissipate energy in the channel, but are expensive to construct and maintain on high-gradient streams with sizeable bedloads. Flow deflection structures include spurs (jetties), sills (permanently submerged spurs) and vanes (panels placed near the bed to generate strong secondary currents). These structures dissipate energy and redirect flows away from the bank.

Bank armor and flow deflection, usually in combination with vegetative methods, are recommended for most sites on Prickly Pear Creek.

Design of Bank Armor.

The most common type of bank protection is rock riprap. One must first determine a reasonable bank angle, not steeper than 1.5:1, for the eroding site; then adopt a design flood. If the armor is used to protect against basal scour and "average" high water, then a 10- to 25-year recurrence interval flood is appropriate for protection of the entire bank slope. A greater (50- to 100-year) design flood may be selected depending upon the site.

Based on flood hydraulics, the median diameter (D50) of the riprap blanket is calculated. Most methods rely on empirical relationships between the shear stress (defined as $\tau_c^* = \gamma d s_e$, where τ_c^* = critical shear stress, γ = specific weight of water, d = mean flow depth or hydraulic radius, and s_e = energy slope) generated by the design flood and the critical threshold of entrainment for rock particles of various sizes. Allowances may be made for a factor of safety in selection of the D50.

To determine the size gradation and thickness of riprap, the ratio of maximum size to the median size (D50) should be about two, and the ratio of the median size to the 20 per cent size should be about two. This provides a smooth, well-graded size distribution with the interstices of larger stones filled by smaller rocks, and results in a coherent, interlocking blanket of rock. The riprap should be thick enough to accommodate the largest stones in the riprap (at least as thick as the diameter of the largest stones).

A filter (gravel or plastic) is placed beneath the riprap to protect the river bank material beneath the riprap from washing out. Gravel filters are normally about one-half the thickness of the riprap and not less than six inches thick. Durable plastic filter cloths have been in use since 1967, but gravel may be cheaper and more effective over the long run. Plastic would also reduce infiltration into the rock and channel bank, hindering any efforts to establish vegetation on the riprap.

While each of the design steps is important, perhaps the most critical is determining the median diameter of the riprap gradation. A comparison of various methods for sizing riprap is given in the following paragraphs.

On Prickly Pear Creek, the design of future channel modifications, including the use of riprap in the channelized, braided reach near the gravel pits on Burnham's land, is of special concern. Six commonly used methods were used to estimate the median diameter for riprap there. The results are summarized in Table A-1, and calculations and details of the methods are on file at Streamworks.

Table A-1.
Median Diameter of Riprap Gradation Using Various Methods*

Method	Median Diameter (feet)
University of Minnesota (Anderson 1970)	0.32
California Division of Highways (1970)	0.39
ASCE Committee (1972)	0.35
U.S. Bureau of Reclamation (1958)	0.06
Simons and Li (1982)	0.2 to 0.4
U.S.D.A. Soil Conservation Service Nomogram	0.42

*Based on a twenty-five-year flood in straight channel segment

The methods produce comparable results with the exception of the Bureau of Reclamation method (1958) which gives a significantly smaller D50. In addition, the latter method is cumbersome, and not recommended for use on Prickly Pear Creek. The Soil Conservation Service nomogram and Simons and Li's incremental shear stress methods are relatively easy to use and give the most conservative results of the six methods. A critical (Shields) shear stress of 0.03 for entrainment is recommended for use with Simons and Li's equation, rather than the 0.06 value commonly accepted for use with the Shields diagram (Andrews 1983).

The design example given is for a straight channel reach. The Soil Conservation Service nomogram makes an allowance for the additional forces present in the channel bends. Simons and Li (1982) provide a graph for evaluating the ratio of shear stress in bends to the mean bed shear stress as a function of channel width and radius of curvature. Either method accounts for the effects of channel curvature on bank shear stress.

Other considerations, such as estimating scour depth, are not fully treated here. A reasonable guideline is to assume scour depths of one-half bankfull depth in straight

and moderately sinuous reaches, and bankfull depth on concave banks of sharp meanders.

Structural Methods For Flow Deflection.

Traditional methods for deflecting flow include the use of wing dams and jetties made from rock alone (riprap or large boulders) or wire-bound rock masses (gabions).

Design considerations include whether to use a permeable or impermeable structure, as well as the height, spacing, and size of rock elements in the deflector and its angle with the stream bank. In general, on straight reaches the spacing of jetties should be no greater than about three to four times the length of the jetty. The following equation may also be used to determine spacing (Charlton 1982):

$$L < \frac{KD^{4/3}}{2gn^2}$$

where L = jetty spacing,

D = depth of flow,

g = gravitational acceleration (meters per second),

n = manning roughness, and

K = constant ≅ 0.6.

In gravel bed rivers, jetties used in groups should be designed with slightly decreasing successive downstream heights, to encourage accretion. They may have horizontal crests or be inclined toward the channel. Methods for determining the size of particles used in flow deflection structures are similar to those for sizing rock riprap.

At remote sites jetties may be constructed from wire baskets (gabions) filled with locally available river gravels. The least expensive and least durable forms use relaltively light gauge wire (hog fencing) as the enclosure. The most durable and expensive forms, on the other hand, use heavy galvanized or plastic coated wire (#10 gauge to 1/4-inch re-bar) to form the baskets (built and welded on site).

Gravel bed rivers cause considerable abrasion, and the range of life expectancies for medium wire (#10 gauge) gabions is only about six to ten years. The long-term success of gabion deflectors is contingent largely upon the establishment of vegetation on the upper and lower banks.

Rock and gabion deflectors dissipate energy, protect the bank, and encourage accretion along the bank. The area between the deflectors is reshaped, mulched and planted.

Flow deflection provides short-term bank protection (five to ten years), giving the vegetation an opportunity to stabilize the bank over the long-term.

Use of Vegetation.

Incorporating vegetation into structural protection designs has much merit. Healthy stands of riparian vegetation improve stream habitat and aesthetics. Grasses protect against surface erosion and fluvial entrainment, while shrubs hinder mechanical failure of banks.

For example, stream velocities near the base of bank grasses may be greatly reduced compared to velocities several inches away near the tips of the grass blades. In many situations the stability or lack of stability of an entire river bank or hillside may depend upon cohesion provided by the root mass of shrubs. One study found that the tensional strength provided by the roots of woody vegetation in a hillside was eight times greater than the internal cohesion provided by residual friction in the soil (Riestenburg and Sovonick-Dunford 1983).

Appendix B presents specific seeding mixtures and planting techniques, and discusses the relationship between vegetation, land use, and bank stability. Further technical information on vegetative stabilization is in Gray and Leiser (1982), and Soil Conservation Service guidelines (USDA Soil Conservation Service 1976b).

The following criteria must be satisfied to use vegetation for streambank protection:

the site must meet the soil, nutrient, and water requirements of the vegetation used;

the growing medium of the vegetation must be protected from surface erosion and fluvial entrainment for about five to ten years, allowing vegetation to become well established; and

the planting of vegetation must be carefully planned and orchestrated so that healthy stock is used. Additional

maintenance (water and fertilization) may be required over the short-term.

To establish streamside vegetation, it is critical to provide a stable growing site protected from surface erosion, basal scour, and mechanical slope failure.

In the Prickly Pear drainage, most moderate and high priority bank erosion sites will require toe protection and reshaping to allow successful revegetation. There are no firm guidelines on how much toe protection is needed or where it may not be needed if vegetation alone suffices. Some guidance is given by the permissible velocities for grassed waterways. While this information applies to grassed, earth waterways (such as irrigation canals), as a first approximation it should also apply for similar grasses established on channel banks.

The range of maximum permissible velocities is from about three to eight feet per second, depending on slope and grass combinations (Chow 1959, Table 7-6). These velocities are mean values for the whole channel. If the velocity is exceeded, then the vegetation will scour and fail. Because the shear stress on the bed of a straight channel is usually greater than that on the banks, the bed will generally erode before the banks, and the three-to-eight feet-per-second range should probably be considered low with respect to the maximum permissible velocities allowable for bank grasses. These values, of course, apply only after vegetation is well-established.

In lieu of established, universal guidelines for determining stream energy environments where various vegetation combinations should and should not be used, the following criteria are suggested for Prickly Pear Creek.

Vegetation (grasses and shrubs) alone may be used in two situations:

1. On channel banks which are in the state of impeded removal. This applies in particular to areas where the 1981 flood has slightly widened the channel or has deposited a berm of excess material adjacent to the channel. Channel banks are usually less than six feet high, and may require reshaping, mulching, and jute netting.

2. On upper bank areas where excessive surface erosion is not a problem. Where surface erosion requires control, the use of terraces and wattling (buried brush bundles staked at right angles to the slope) may be required. Details are given in Gray and Leiser (1982).

Vegetation in combination with bank armor may be used in most situations. On straight and meandering channel reaches, the lower bank (about two to four feet above low water) may be protected with bank armor, with vegetation planted on the upper bank area. Two general methods are available: placement of rock riprap; and staking of brush matting.

Rock riprap is paced (normally dumped from truck, or placed by machine) on a regraded channel bank. Allowance is made for scour (assume channel can scour to one-half bankfull depth in most reaches and to bankfull depth on bends) along the edge of the bank by excavating a narrow trench (usually three feet wide) below the stream bed and placing the rock below the present stream elevation. In addition to protecting the basal area of the bank from entrainment, this "key" also buttresses the slope somewhat against mass failure. Vegetation may then be planted on the upper bank area.

Where surface erosion will be a problem on the upper bank where upper bank entrainment problems are anticipated, the vegetation and mulch should be secured with staked jute netting.

Brush matting woven into bundles and staked to the bank is another type of bank armor. Standard designs normally include a bank side slope no greater than 1.5:1; brush matting about one to two feet thick staked to the bank; and rock riprap placed on the toe of the bank to protect the basal area from scour and the mat from undermining and lift.

The matting, usually shrubs, is placed with the butts upslope and the tops pointed slightly downstream to minimize flow resistance of the matting. Shrubs are planted before the mat is placed, then the matting is woven around the plantings. The reverse, while possible, is more difficult.

Initially, the success of the brush-mat method is limited by how well the matting is anchored. Live or conventional wooden stakes are well-adapted to the upper bank area, where moderately cohesive, fine-grained sediments are easily penetrated and provide considerable strength. In very cohesive materials, such as clay, or totally uncohesive materials, such as gravel, anchoring the mat is a problem.

Brush matting may be anchored to mechanically stable materials by using longer stakes or "dead-man" anchors.

Composite banks are typical on Prickly Pear Creek upstream from York Road. In the upper bank, staking will anchor the mat. Matting overlying coarse gravels in the lower bank can be anchored in several ways. The brush mat may be extended slightly beneath the channel bed, and covered with a shallow berm of riprap at the toe of the

bank. This protects the toe from scour and prevents flow from penetrating beneath the brush. For upper bank areas made of gravel and cobbles, staking may be used, employing short (about three feet long) sections of one-half-inch re-bar driven with a sledge hammer.

Some bouldery banks will even prohibit staking with re-bar, requiring more extensive use of rock on top of the matting to hold it in place. An alternative is to use riprap alone on the lower, cobble bank, and brush mat on the upper, cohesive bank.

The use of organic matter for flow deflectors is not common, although some measures rely on brush or logs as structural elements to deflect flow. These methods include buried tree jetties, cabled tree revetments, "jetted" willow poles, and driven piles with brush wired next to the bank.

These methods may be useful in the lower part of Prickly Pear, where bank erosion is extensive and the channel bed is sand to fine gravel. In the upper sections of the stream, where the bed is mostly gravel and cobbles, the driving of wooden piling is impractical. Also, on the higher-gradient reaches where scour may be a problem, these methods may not protect the basal area of the bank. In general, these methods are not recommended for use on Prickly Pear or its tributaries. A possible exception is the use of substantial logs for flow deflection where access by machinery is limited.

APPENDIX B.

REVEGETATION METHODS RECOMMENDED FOR PRICKLY PEAR CREEK

Revegetating or enhancing vegetation growth on streambanks is a high priority for the rehabilitation of Prickly Pear Creek riparian and aquatic ecosystems. In some areas, the riparian vegetation has been altered or removed by such as highway construction, railroad construction, mining, grazing, and suburban developments. The reduction in the canopy coverage and species diversity of the riparian vegetation has contributed to erosion and mass wasting of streambanks, reducing the quality of the aquatic environment.

All biological and physical methods suggested for use along Prickly Pear Creek, based upon reviews of technical literature on reclamation and revegation, are relatively cost efficient. A number of previous studies have recommended specific techniques for stabilizing and revegetating streambanks and riparian zones. These studies include Workman (1974), Stiller and Associates (1983), Environmental Research Technology/Ecology Consultants, Inc. (1979), Stipo (1979), Steucke (1982), U.S. Soil Conservation Service (USDA Soil Conservation Service 1976a,b) and Sindelar (1973).

Workman's Revegetation Experiments on Prickly Pear Creek.

Dennis Workman (1974) of the Montana Department of Fish, Wildlife, and Parks conducted revegetation experiments from 1968 to 1973 on Prickly Pear Creek, studying where riparian vegetation had been removed and the stream rechanneled during construction of Interstate 15. In 1968 Workman planted willow sprigs along 3,018 feet of disturbed, steep streambanks. He had poor success in establishing the plants, because of unstable soil and bank erosion. In April 1971, rock and soil berms were constructed by backsloping steep, eroding banks and piling the soil removed during backsloping into one- to two-foot-high berms, by the stream. Willow, red-osier, dogwood, rose, and snowberry were planted and a native grass mixture was broadcast seeded on the berms.

Spring-planted willows achieved 70.2 per cent success, the best shrub survival for the first year. On some berms with good-quality soils, vegetation from natural seeding became extremely dense. On sites with sandy loam soils, natural vegetation became established very rapidly, while revegetation was limited on clay soils derived from decomposed granite.

A recent field trip (October 18, 1983) with Workman to

the revegetation study sites revealed that the constructive berms, in conjunction with backsloping steep banks, successfully established vegetation and stabilized soils. All of the berms constructed by Workman survived the 1981 flood and are now densely vegetated with diverse stands of grass and forb species.

Although the berms are well vegetated with grasses and forbs, the growth of woody species is limited on both the backsloped banks and the berms. Occasional small alders, willows and rose occur but none are growing well or proliferating. Close examination of the shrubs showed that all have been very heavily browsed by deer. This has apparently limited the growth of some woody species along the stream and may inhibit future revegetation efforts.

Recommendations for Seed Application.

Streamside berms and streambanks that have been backsloped should be raked smooth in preparation for seeding. If the area to be planted develops a crust prior to seeding, the soil surface should be lightly disced, harrowed, or otherwise scarified on the contour to permit seeding. Planting by drilled or broadcast seeding should follow immediately.

Drilling seed is preferable to broadcast seeding because lower seeding rates are required and the seed can be planted at the proper depth for various species. Drill seeding also improves moisture infiltration and storage, increasing the chance of establishing seedlings on relatively dry microsites.

If drilling seed is not feasible because a site lacks access or is too small for equipment, broadcast seeding should be done manually with cyclone-type bucket spreaders or a mechanical seed blower. Seed should be mixed within the spreader frequently during operation to prevent smaller and denser seeds from settling.

After broadcast or drilled seeding, weed-free straw mulch should be applied at a rate of 0.5 to 1.0 ton per acre and crimped in at a depth of four to eight inches to prevent wind loss. Mulches are applied to seeded areas to retard erosion, moderate surface temperatures, retain moisture, and provide shade for seedlings. On slopes in excess of 3:1, jute netting should be spread over the seedbed and straw mulch, and anchored to prevent disruption by wind or water.

Seeds should be planted in either the late fall (after October 15) as dormant plantings or in the early spring (before May 15). Late fall plantings are usually preferable

because they can be done closely after recontouring, reducing the need to visit and disturb the site more than once. Recontouring or use of heavy equipment should be done in the fall when grasses and forbs are dormant and when soils are dry to prevent damage to adjacent soils and vegetation.

Recommended Seed Mixtures.

Based on literature reviews and site studies to determine the dominant species along Prickly Pear Creek, Streamworks recommended a seed mixture for planting on all recontoured banks and berms (see table B-1). Kentucky bluegrass is a common sod-forming species, particularly in heavily grazed areas along Prickly Pear Creek. This easily established grass is recommended by the U.S. Department of Agriculture (USDA Soil Conservation Service 1979) for planting in grassed waterways. Streambank wheatgrass, a native perennial species, is a vigorous sod-former, relatively easily established (even on dry sites) and recommended for pond and irrigation banks (Long 1981).

Smooth brome is dominant on many sites in Prickly Pear Creek. Easily established, it is a vigorous sod-former, able to withstand water-saturated soils in the spring, adapted to a wide variety of sites, and excellent for wind and water erosion control. Western wheatgrass, a common species along Prickly Pear Creek, adapts to medium and clayey soil textures. Able to withstand silt deposition, it forms a dense sod and is relatively drought-tolerant.

Reed canarygrass grows on some wet sites along Prickly Pear Creek where cattle grazing is infrequent or absent. This species is a sod-former which can grow well in water-saturated soils or on drier streambanks, and will emerge through six to eight inches of sediment.

It is recommended that all seed rates be applied as pure live seed (PLS); therefore, the per cent purity and per cent germination of commercial seed sources must be known before preparation of seed mixtures. The following formula can be used to calculate the relationship between commercial seed and PLS:

$$\text{Pounds of Commercial Seed per Acre} = \frac{\text{Pounds of Pure Live Seed per Acre}}{(\text{Percent Purity})(\text{Percent Germination})}$$

No seed should be applied during high winds, rainy weather, or when the ground is frozen.

Table B-1. Seeding Mixture Recommended for Recontoured Banks and Berms.

Species	Seeding Rate* (Lbs/Acre)
Kentucky bluegrass	1.0
Streambank wheatgrass	6.0
Smooth brome	3.0
Western wheatgrass	6.0
Reed canarygrass (zone seeded)	2.0
Total	18.0

*Double seeding rate if broadcast seeded.

Recommended Shrub Plantings.

Vigorous growth of grasses and forbs must be reestablished on eroded banks along Prickly Pear Creek for maximum rehabilitation. Establishment of the grasses, forbs, and woody species prevents surficial erosion and mass movement. Woody plants primarily stabilize soil by root reinforcement:

> The intermingled lateral roots of woody plants tend to bind the soil together in a monolithic mass. On slopes, the vertical root system (i.e., the main tap root and secondary sinker roots) can penetrate through the soil mantle into firmer strata below (e.g., fractured or disintegrated bedrock), thus anchoring the soil to the slope and increasing resistance to sliding. (Gray and Leiser 1982)

It is essential to establish woody plants to increase soil stability and improve aesthetics and fisheries habitat. Shrub plantings are recommended along Prickly Pear Creek, but several limitations should be considered. For example, Workman (1974) found that fall plantings of willow cuttings along Prickly Pear Creek were approximately 70 per cent successful, but subsequent field visits (October 1983) to the sites show that very few of the willows (or other shrubs planted) are surviving. The relatively low rate of shrub reestablishment is probably caused by extremely heavy deer browsing.

Reestablishment of willows and other woody species through natural seeding is by heavy cattle use limited on some areas along the stream. Newly planted shrubs are particularly vulnerable to both grazing and trampling, so it is important to prevent destruction of the newly planted shrubs by domestic stock, deer, or rodents. Collecting, preparing, and planting willow sprigs, bare root stock, or containerized stock are relatively labor intensive and can be quite costly. If livestock use cannot be excluded on certain sites until shrubs are established, time and money spent on planting shrubs will be wasted.

On sites where deer browsing of streamside shrub communities is extremely heavy (as determined by site visits), it may be advisable to plant species which are relatively unpalatable to deer, or to seed with grasses. It is not cost effective or feasible to prevent deer use of shrubs by fencing or other mechanical means.

Planting willow and alder sprigs is recommended to reestablish woody vegetation adjacent the creek. The planting of these species is suggested because of the past success with their establishment and because locally adapted planting stock is available at many locations along the creek.

Willows and alders are phreatophytes (plants whose rooting systems penetrate the ground water or capillary fringe of the ground water), and must be planted so that their root systems can penetrate the ground water. Therefore, willow and alder sprigs should be planted only on soil which lies within two to three feet of the stream surface during low water periods.

On the higher streambanks, shrubs such as snowberry, rose, golden currant, Russian olive, and caragana should be planted. These species now grow along the creek at some sites and are relatively easy to establish. Snowberry and rose can be obtained from nurseries or by transplanting native individuals. All planting of native and nursery stock should be done in the early spring (before May 15), after the frost has left the soil. All plants should be placed in the soil to form a basin which gently slopes from the outside of the planting hole to the seedling stem to aid in water catchment. All plants should be watered at the time of placement and mulched with straw that is free of noxious weed seeds.

Willow and alder shoot cuttings should be collected from branches or main stems (1/4 to 1 inch in diameter) with soft pliable bark and a terminal bud. Cuts should be at a 45 degree angle to provide a large surface for root production. All lateral branches should be trimmed from the shoot cuttings.

Immediately after collection, shoot cuttings should be covered with moist burlap or the cut ends submerged in water to avoid drying out. It is best to plant the cuttings on the same day they are collected. To prevent damaging the shoot, a steel rod should be used to make a hole in the soil (12 to 18 inches deep) before the shoots are planted.

Recommendations for Recontouring Streambanks.

Many vertical eroding banks along Prickly Pear Creek are completely devoid of vegetation. By recontouring the banks (backsloping), reseeding, and mulching, the possibility of stabilizing the slopes with vegetation is greatly enhanced.

For backsloping to be feasible, however, the removed soil must be disposed of or used. On sites along the creek where the eroded banks are not directly impinged upon by water at normal flows and where the shoreline is exposed, it may be possible to use excess soil to construct berms adjacent the stream. The berms would provide a flat surface on which to establish vegetation and allow water to percolate down to the root zones of woody species such as willow, alder, and cottonwood.

To determine the feasibility of backsloping and berm construction, one should consider the height of the vertical bank, width of exposed shoreline, and the potential for excess soil disposal through spreading on upper bank. For example, on eroded vertical banks five feet high or less with an exposed shoreline or gravel bar six feet wide or wider, backsloping is recommended. Most of the excess soil removed could be used for berm construction.

On vertical banks seven feet high or higher, excess soil disposal could become a problem. For instance, consider the following calculations for vertical streambanks of two, four, and seven feet high.

Backsloping (3:1 slope) a vertical bank 2 feet high and 10 feet long would result in 15 cubic feet of excess soil. This soil could be used to construct a berm 1.0 foot high, 1.5 feet wide, and 10.0 feet long. Backsloping would begin one foot above the bottom of the bank to allow for construction of a berm one foot high.

Backsloping (3:1 slope) a vertical bank 4 feet high and 10 feet long would result in 135 cubic feet of excess soil. Assuming that backsloping would begin 2 feet above the bottom of the bank, a berm 2.0 feet high, 6.0 feet wide and 11.25 feet long could be constructed.

Backsloping (3:1 slope) a vertical bank 7 feet high and 10 feet long would result in 370 cubic feet of excess soil.

Assuming that backsloping would begin 2 feet above the bottom of the bank, a berm 2 feet high and 6 feet wide and approximately 31 feet long would have to be constructed to dispose of the soil. Or, if a shorter berm were constructed, excess soil would have to be disposed of by spreading it on upper streambanks in a way that would minimize disturbance of existing vegetation. Determining the feasibility of backsloping vertical banks of seven feet or higher should be made based on site-specific information.

To reduce the excess soil from backsloping, a steeper slope could be constructed. If a 2:1 backslope were constructed for a 7-feet-high by 10-feet-long vertical bank, 250 cubic feet of soil would have to be disposed of or used. The problem of soil disposal would be alleviated, but the steepness of the slope would provide additional stabilization problems. Hydromulching or jute netting would be required to stabilize soil until vegetation became established.

APPENDIX C.

DESCRIPTIONS AND RECOMMENDATIONS FOR INDIVIDUAL PROBLEM SITES

Site Descriptions and Treatments.

The tables in this appendix list all of the serious problem sites along Prickly Pear. Each of the sites was identified by field work, review of files from the Lewis and Clark County Conservation District, conversations with some landowners, and study of previous reports on Prickly Pear Creek (Montana DHES 1981, Husby and Moore 1982)

Each individual problem site was assigned a number and plotted on one of a series of large-scale (1 inch = 250 feet) aerial photos of the creek. We used the site compilations of the Montana Department of Health and Environmental Sciences (Montana DHES 1981) as a starting point, adding to or updating information directly on the aerial photo maps, but retaining their site-numbering system. These photos are on file and available for examination at the Lewis and Clark County Conservation District (Federal Building, Helena). Persons interested in locating a specific site should examine these photos.

The suggested work and priorities for sites listed in this appendix is not considered final. Landowners and others may well have information that would change the assessment of certain areas. In future years, floods, natural revegetation, droughts or rainy spells, or changes in land use may require reexamination of the problem areas. A stream such as Prickly Pear is dynamic, not static, and we expect that at least some of the problems will correct themselves naturally, while other problems may develop.

Table C-1 summarizes site information and recommended treatments for individual problem sites. Column headings are explained as follows:

Column 1. Site number. Corresponds to designations used by the Montana Department of Health and Environmental Sciences (1981). The first number indicates the photo, the second is the site on the photo. New sites are indicated by adding a decimal number to previous site designations.

Column 2. Priority. Sites were assigned relative priorities of high (H), medium (M), or low (L).

Column 3. Problem. Problems at each site were classified five ways:

- D Debris needs cleanup;
- S Bank Protection for sediment control is needed;
- E Bank Erosion threatens structure;
- F Fisheries habitat needs improvement;
- B Bridge or culvert constricts flow.

Column 4. Recommended treatments. Cost estimates were made for a number of rehabilitation treatments recommended for Prickly Pear Creek. They are based on calculations of cost per unit of work, as given below. Abbreviations for the various recommended treatments are also given.

	Treatment	Units	Cost
A.	Reshape bank	ea	$500.00
B.	Riprap bank base	cu yd	20.00
C.	Riprap channel bank	cu yd	15.00
D.	Rock jetties	cu yd	25.00
E.	Gabions	cu yd	40.00
F.	Boulders, 3 ft diam.	ea	100.00
G.	Alter Channel	cu yd	6.00
H.	Access Bridge	ea	5000.00
I.	Slope drainage	lineal ft	5.00
J.	Retaining Wall	cu yd	20.00
K.	Clear debris	ea	500.00
L.	Sprig-live stake	sq ft	0.75
M.	Revegetate	sq ft	0.20
O.	Fence	lineal ft	1.00
P.	Log jetties	ea	800.00
Q.	Habitat structure	ea	1750.00

Column 5. Access. The following measures of access were used:

Excellent	Can drive truck or backhoe to site;
Good	Can get to bank with some effort;
Fair	Site is accessible to heavy equipment, but may require construction of access road for trucks;
Poor	Requires major construction work (road, bridge, etc.) to each site.

Column 6. Reach length. The overall channel length; used primarily for longer sites.

Column 7. Bank length. The length of bank affected, allowing for keying in materials.

Column 8. Bank height. The mean bank height, or the range of heights, at a site.

Column 9. Bank area requiring vegetation. The area as calculated from mean bank height and length, generally assuming a 2:1 slope.

Column 10. Volume of rock needed for gabions or flow deflectors, assuming 5 cubic yards per jetty above East Helena, and 8 cubic yards below East Helena. Jetties are assumed to have a spacing of 30 to 40 feet.

Column 11. Volume of rock for riprap. An estimate based on length of bank and unit volume of 0.8 cubic yards per foot of streambank, for treatment B.

Table C-1. SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Sheet 1

Channel Reach	Site[1] No.	Priority[2]	Problem[3]	Recommended[4] Treatment	Access[5]	Reach[6] Length Ft.	Bank[7] Length Ft.	Bank[8] Height Ft.	Bank Material	Bank Area[9] Requiring Veg.	Vol. of Rock[10] for Gabions of Flow Deflections	Vol. of Rock[11] for Rip-Rap
	39-3-RG 39-4-RG 39-5-RG	M	D S S	F,L	Ex.	2500			Sandy gravel	60% of reach= L = 3000 ft.		
1	39-6 EB 39-7 MW	M	S S	D,L	Ex.		250	3-5	Sandy gravel	L = 300 ft.	4 Jetties=20 c.y.	
	39-8 EB 39-9 EB	M	S S	A,D,L,M	Good		175	5	Sandy gravel	M = 2000 ft.[2] L = 200 ft.	6 Jetties=30 c.y.	
	38-3.1 B	M	E		Ex.							50 c.y. R.R.
	38-3.2 EB	M	S	A,D,L	Ex.		40	5	Silty sand	L = 60 ft.	2 Jetties=10 c.y.	
	38-5 EB	M	S	A,L	Good		40	4	Silty sand	L = 60 ft.		
2	38-6 EB	H	S	B- then push undercut bank down on Rip-Rap & plant (M)	Good		50	8-12	Silty sand	M = 1000 ft.[2]		40 c.y. R.R. 10 c.y. gravel filter
	38-6.1 EB	H	S	" " "	Good		50	8-12	Silty sand	M = 2000 ft.[2]		40 c.y. R.R. 10 c.y. gravel filter
3	37-3 EB	M	S,E	A,B,D,M	Ex.		100	5-15	Sand gravel dredge pile	M = 1500 ft.[2]	3 Jetties, 3 c.y. ea. = 9 c.y.	80 c.y. R.R. 20 c.y. gravel filter
	37-4 EB	H	E,S	A,B,L,M	Ex.		250	5	dredge pile & gravel	M = 2700 ft.[2] L = 300 ft.		200 c.y. R.R. 50 c.y. gravel filter

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Sheet 2

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
	37-5 EB	H	S	A,B,L,M	Ex.		250	5	Comp. sand & gravel over pebbles	M = 2700 ft.^{2}		200 c.y. R.R. 50 c.y. gravel filter
	37-7 EB; 37-5.1 EB	M	S S	A,D,F,L	Ex.		250	3	Pebbles overlain by silty sand	L = 300 ft.	Small Jetties=2c.y. ea., 1 every 30 ft. = 18 c.y.	
	37-8 EB	H	S	A,D,F,L,M	Good		270	4-7	Sandy over pebbles & boulders	M = 2900 ft.^{2} L = 300 ft.	" " " " " "	
	37-9 EB	M	S,E	A,L	Ex.		50	4	" " " "	L = 50 ft.^{2}		
	37-10 EB (36-1 EB)	H	S	A,D,F,L,M	Good		80	4	Sandy gravel	L = 100 ft. M = 800 ft.^{2}	3 Jetties=15 c.y.	
3 (cont.)	36-2 EB	H	S	A,D or E,L,M	Fair		85	8	Sandy gravel	L = 100 ft. M = 800 ft.^{2}	3 Jetties=15 c.y. 3 gabions struct=15 c.y.	
	36-3 EB	M	S	A,E,L	Poor		100		Sandy gravel	L = 120 ft.	3 gabions struct=15 c.y.	
	36-4 EB	H	S	B, hen pull back top of bank & plant	Good		50	15	Sandy gravel	L = 70 ft. M = 100 ft.^{2}		60 c.y. R.R. 15 c.y. gravel filter
	36-5 EB	M	S	L	Poor		250	1-2	Dredge pile material	L = 300 ft.		
	36-6 EB	M	S	O	Good		50	1-2	Sand			
	36-7.1	M	S	O	Fair							
	36-9 EB	M	S	A,M	Poor		30	5	Sandy gravel	M = 240 ft.^{2}		
	36-10.1 EB	M	S	F,L	Poor		150	3-5	Silt, sand gravel	L = 200 ft	5 small Jetties=15 c.y	

Sheet 3

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
3 (cont.)	36-15 EB	M	S	A,B,L,O	Fair		100	3-5	Gravel, sand cobbles	L = 150 ft.		80 c.y. R.R. 20 c.y. gravel
	35-4 EB	L	S	L	Poor		100	3-5	Gravel, cobbles	L = 150 ft.		
	35-9 EB	L	E	B	Ex.		120	3-4	Gravel cobbles			60 c.y. R.R.
	35-10 EB 11 EB	L	S S	B,L	Ex.		400	3-10	Sand, cobbles, boulders	L = 500 ft.		.3 c.y./ft. bank=120 c.y.
4	35-12 EB	M	S	A,M	Ex.		40	5-7	Silty sand	M = 600 ft.^{2}		
	35-15 EB	H	E,S	L,N,M	Poor		75	20	Sand, gravel	M - 2000 ft.^{2} L = 100 ft.		
	34-3 EB	M	S,E	A,B,L,M	Good		40	3-8	Sand & silt	M = 400 ft.^{2} L = 100 ft.		40 c.y. R.R. 10 c.y. gravel filter
	34-6 EB 34-7 EB 34-8 EB	M	S S S,E	A,D,L,M	Fair to Good	600		4-7	Silt, sand & dredge	M = 6000 ft.^{2} L = 700 ft.	30 Jetties=150 c.y.	60 c.y. R.R.
5	34-19 EB	H	E,S	A,B,L,M	Ex.		70	9	Silt, sand	M = 900 ft.^{2} L = 100 ft.		70 c.y. R.R. 15 c.y. gravel filter

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
	33-0.1 EB	M	S	A,D,L	Good		60	4	Silt, gravel & cobbles	M = 600 ft.^{2} L = 100 ft.	3 Jetties=15 c.y.	
	33-6 EB	M	S	B,L	Good		50	5		L = 60 ft.		25 c.y. R.R.
	33-7A, 8A	"	S	L	Good		Both Banks 500 Ft	13-15	railroad slag	L = 800 ft.		
	33-9.1 EB	H(1 So.)	S	A,B,L,M	from inter-state or railroad grade		60	3-5	sand, silt & cobbles	M = 400 ft.^{2} L = 80 ft.		50 c.y. R.R. 10 c.y. gravel
	33-9.1 EB	H(2 MD.)	S	A,B,L,M,N	" "		80	15	" " " "	M = 1000 ft.^{2} L = 100 ft.		70 c.y. R.R. 15 c.y. gravel
5 (cont.)	33-9.1 EB	H(3 No.)	S	A,B,L,M	" "		170	5	" " " "	M = 1700 ft.^{2} L = 200 ft.		140 c.y. R.R. 40 c.y. gravel
	33-11 EB	H(1 So.)	S	L,M	Fair to Poor		225	4	silty, sand	M = 1800 ft.^{2} L = 300 ft.		
	33-11 EB	H(2 No.)	S	A,B,L,M,N	" " "		240	20	silty, sand	M = 5000 ft^2 L = 500 ft. N = 1800 ft.		190 c.y. R.R. 60 c.y. gravel
	32-3 R	M	S	L	Ex.		80	10	Rip Rap	L = 100 ft.		
	32-4 EB	H(1 So.)	S	A,C,L,M	Fair		60	4	Sandy	M = 600 ft.^{2} L = 100 ft.	3 Jetties=15 c.y.	
	32-4 EB	H(2 No.)	S	A,D,L,M	Fair		110	10	Sandy	M = 1400 ft.^{2} L = 130 ft.	4 Jetties=20 c.y.	
	32-5.1 EB	M		D,M	Good		170	5-10	Sandy	M = 1400 ft.^{2} L = 200 ft.	3 Jetties=9 c.y.	

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Sheet 5

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. or Rock for Rip-Rap
	32-6 EB	M	S	L	Good		90	5-10	Small Rip-Rap	L = 120 ft.		
	32-6.1 EB	M	S	D,M	Good		150	5-10	Railroad Fill	M = 1200 ft^2	4 Jetties=20 c.y.	
5 (cont.)	32-7R, 8R, 9R, 9.1R, 10R, 11R, 12R, 13R	L	S	L,M	Good	3500		3-10	Rip Rap, cobbles	M = 15,000 ft^2 L = 3000 ft		
	31-4 EB	M	E	D,L	Good		150	3	Silt, sand	L = 200 ft.	5 Jetties=25 c.y.	
	31-6 EB	L	E,S	D,L	Good		150	3	Silt, sand	L = 200 ft.	5 Jetties=25 c.y.	
	31-11 EB, 12 EB, 15 EB, 16 EB	M	E,S	A,BorDorE, L,M	Ex. to Good	1200		3-6	Silt, sand gravel	50% L=1200 ft. M = 4000 ft^2		400 c.y. R.R. 100 c.y. gravel filter
6	31-20D	L	E,S	L,M	Ex.		100	10	Rip Rap	L = 120 ft. M = 800 ft^2		
	31-22A	L	E,S	L,M	Ex.		200	10	Rip Rap	L = 220 ft. M = 2000 ft.		
	31-27A,R	L	S,E	M	Ex.		40	10	Rip Rap & Sand	M = 500 $ft.^2$		
	30-1A, 30-2R, 30-3R	M	F	F,L	Ex.	3000		5-10	Rip Rap & Cobbles	L = 6000 ft.	15 riffles created w/boulders = 60 boulders	

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
	30-4 EB	M	S	L	Ex.		100	5-10	Cobbles	L = 120 ft.		
	30-5.1 EB	M	S	L	Ex.		400	8-10	Cobbles Rip Rap	L = 450 ft.		
6 (cont.)	30-6 R	M	E,S	A,B,L	Ex.		200	5-10	Rip Rap Cobbles	L = 250 ft.		100 c.y.
	30-9.1 EB	L	S	L	Good		200	5	Sand, gravel	L = 250 ft.		
	30-9.2 EB	L	S	L	Good		60	5	Sand, gravel	L = 80 ft.		
	29-1A	M	E,S	L	Good to Poor	2500		1-4	Sand, gravel	50% of reach, both banks or 2500 ft. + 1000 ft. misc. islands		
	27-6 EB	H	E,[illegible]	A,B,L	Ex.		130	4	Sand, Silt Gravel	L = 150 ft.		130 c.y. R.R. 30 c.y. gravel
	27-7R 7.1 EB	H	S	A,B,F,L	Good		100	10	Comp. RR over cobbles	L = 120 ft.		100 c.y. R.R. 20 c.y. gravel
	27-10 MW	L	S	L	Good		80	5-7	Sand, Silt gravel	L = 100 ft.		
7	27-13R	L-M	S,B	H	Ex							
	27-15E	M	S	A,D,L,M	Ex.		30	4-8	Placer mine tailings (recent)	M = 400 $ft.^2$ L = 50 ft.	2 Jetties=10 c.y.	
	27-16R	M	S	A,M	Good		[illegible]	4-6	Rip Rap [illegible] bank.	M = 1600 $ft.^2$		

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
7 (cont.)	27-171	L	E	F	Fair				Rip Rap			8 c.y.
	27-18 NB	M	S	L&M (shrubs) for shade of H_2O	Fair		100	4	Gravel	L = 120 ft.		
	27-24 Mw	L	S	L	Poor		80	6-8		L = 100 ft.		
	27-25 Rg	L-M	S	L	Fair		200	5-7		L = 220 ft.		
	26-10 Rg	L	S	L	Good		300	4	Gravel	L = 350 ft.		
	26-12 R	M	E,S	Re-enforce existing Rip-Rap & soil & Veg. on narrow beam	Ex.		180	4-12	Gravel Rip Rap	M = 750 ft^2 L = 200 ft		60 c.y. R.R. 30 c.y. fill
8	25-2R	L-M		L,M	Ex.		160	8	Rip Rap	L = 180 ft.		fill = 100 c.y.
	25-4 EB	L-M	S	L,M	Ex.		150	10	Rip Rap			fill = 100 c.y.
	25-5 EB	L-M	S	L	Ex.		90	4-7	Sand, gravel	L = 120 ft.		
	25-7 R	L-M		L	Ex.		180	4-8	Rip Rap	L = 200 ft.		
	25-7.1 EB	M	S,E	DorF,L	Ex.		270	5	Sand to boulders	L = 300 ft.	9 Jetties=45 c.y.	
	25-8R	L-M		L	Ex.		130	5	Rip Rap	L = 150 ft.		
	25-9 R	M	E,S	Landscaping L,M	Ex.					M = 1500 $ft.^2$ L = 200 ft.		Approaches = 60 c.y. R.R

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Sheet 8

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
9	25-17 EB	M	S	A,B,K,L	Good		150	8	Sandy Gravel	200 ft = L		140 c.y. RR 30 c.y. gravel filter
	24-1 EB	L	S	L	Good		90	4	Sod Blocks & Grass	110 ft = L		
	24-2 EB	L	E,S	Reinforce rip rap	Good		80	10	Rip Rap	100 ft = L		40 c.y. RR
	24-4F, 5 EB	H	S	A,B,L,M	Ex.		100	5	Silt & Sand	1000 ft^2 = M 120 ft = L		80 c.y. RR 20 c.y. gravel filter
	24-6 EB	L	S	L	Ex.		120	5	Sand & Gravel	140 ft = L		
	24-7 EB	H	S	A,B,L,M	Good		220	8-10	Silt & Sand	2500 ft^2 = M 250 ft = L		180 c.y. RR 40 c.y. gravel filter
	24-8 EB	M	S	A,B or E,L	Fair		90	7	Sand, Silt Gravel	120 ft = L		80 c.y. RR 20 c.y. gravel filter
	24-11 R	L	S	L	Poor		85	7	Rip Rap	100 ft = L		
	24-12 EB	H	S	A,B or L,M,N	Poor		420	12	Sand, Silt Gravel, grus	5000 ft^2 to 1000 = M L = 500 ft		200 c.y. RR 75 c.y. fill
	24-16 MW	H	S	A,B or E,L, M,N	Poor		570	12-20	Fract.& Weathered Granite Bedrock	N = 2280 ft 11,400 ft^2 = M		270 c.y. RR 100 c.y. fill
	24-17 MW	H	S	B or E,I,L,M	Poor		170	20	Silt, Sand Clay	4000 ft^2 = M 200 ft = L		90 c.y. RR 30 c.y. Fill

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
9 (contd.)	23-2P	M		L	Fair		250	4-8	Rip-rap	300 ft = L		
	23-5R	M	S	L	Fair		200	4-8	Rip-rap	250 ft = L		
	23-6MW, 7EB	H	S	E or J & L,M,N	Fair		300	10	Silt, Sand Gravel	8000 ft^2 = M 250 ft = L 3000 ft = N	140 c.y. R.R. + 80 c.y. fill for 4 x 3 ' rock-berm	
	23-8 EB	L	S	L	Fair		40	4	Minor rip rap silt sand, gravel	60 ft = L		
	23-12 R	L	S	O,E or F,L	Poor		50	8	Silt, sand gravel	70 ft = L	2 jetties = 10 c.y.	
	23-13.1 EB	L	S	O,L,M	Poor		50	15	Silt, sand	60 ft = L 700 ft^2 = M	2 jetties = 10 c.y.	
	23-14 R	L	S	L,M	Fair		170	5	70' rip rap 100' gravel	200 ft = L 600 ft^2 = M		
10	21-1 R	M		M	Good		250	3-10	Sand & silt	2000 ft^2 = M		
	20-2 R	L		M	Ex.		230	16	Rip Rap	M = 3700 ft^2	Vol. of fill = 270 c.y.	
	20-4 R	M	O	K	Good				Rip Rap fine alluvium			
	20-4.1 EB	H	S	M	Good		210	slope length 100	Fine alluvium Rip Rap	M = 21,000 ft^2		
	19-2 EB, 2.1 EB	H	S,E	A,B,L,M	Ex.		350	13		6000 ft^2 = M 400 ft = L	1,300 c.y. exc. & haul	280 c.y. FP 70 c.y. gravel

Table C-1(cont.) SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
11	18-1 EB	M	S	A,D,L,M,O	Fair		570	75 = 5-12 500 = 4	Sandy gravel	6000 ft^2 = M 650 ft = L	24 jetties = 120 c.y.	
	18-2 EB, 3 EB, 4 EB 5A, 6 EB	M	S	G,D,L,M,O	Fair to poor	1000'		4-8	Mainly fine aluvium Bedrock at 5A		Flow deflection for 500 ft = 120 c.y.+ minor channel exca vation to improve alignment 3 extra days with front end loader	
	18- 7R, 8R, 9R 10LB9	M	S	A,D,L,M,O	Good to Fair	750		3-10	Aluvium minor bed-rock	L = 1800 ft M = 50% of reach (both banks) = 6000 ft^2	80 c.y. for flow deflection	
	17- 1R, 2R 3R, 4 ER, 5R 6R, 7R	M	S	A,D,L,M,O	Good to Fair	1300		4-10	Sandy gravel	2600 ft = L 50% reach, M = 6500 ft^2	100 c.y.	
	17- 8 EB, 9EB, 10EB, 11R	M	S	D,L,M,O	Good to Fair		1200	4-6	Sandy gravel	2400 ft = L 50% reach M = 7200 ft^2	80 c.y.	
12	16-8 thru 11 & 15-1 to 5EB	H	S S	J,L,M	Good to Fair		1300	3-6	slag	West bank = 13,000 ft^2 = M 1500 ft = L East bank 500 ft = L	Rock Berm 1200 ft x 6ft x 9 ft x 3 ft = 2300 c y. Fill = 1300 ft x 2ft x 6ft = 600 c.y.	
13	14-101	H	E,S	A,B,L,M	Good		375	4 to 6	Rip rap Alluvium	6000 ft^2=M L= 400 ft		450 c.y. RR 130 c.y. Gravel filter
	13-6EB, 7AR	M	S	A,M,L,O	Good		600	4 to 6	Levee Alluvium	L= 600 ft M= 6000 ft^2		
	13-16.1EB 16R	M	E	A,B,L,M,O	Ex.		120	3 to 4	Sand, fine & gravel	700 ft^2 = M 130 ft = L		120 c.y. RR 30 c.y. gravel filter
	13-20EB	M	S	O,L,M,O	Good		150	4 to 5	Clay, sand silt, grass sod on top	1500 ft^2 = M L = 180 ft	8 jetties = 64 c.y.	
	13-21EB	M	S	A,B,O,L,M,O	Good		125	5	Clay, sand silt, grass sod on top	1250 ft^2 = M L = 150 ft	5 jetties = 40 c.y.	50 c.y. RR 10 c.y. gravel
	12-31.0 40		de-watering begins here									
	12-6EB-7EB	[illegible]	S	D,L,M,O	Good		250	3	Fine Alluvi.	M= 6250 ft^2 L = 3[illegible] ft	10 jetties 80 c.y.	

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Sheet 11

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
13 (contd.)	12-8.1EB 8.2EB 8.3EB 9EB	M	S	O,L,M,O	Fair		900	3-5	Fine to coarse Alluvium	M = 5400 ft^2 L = 900 ft	20 jetties = 160 c.y.	
	12-10EB	M	S	O,L,M,O	Fair		1000	3-4	Sod capped w/ fines	M = 6000 ft^2 L = 1000 ft	30 jetties = 240 c.y.	
	12-11EB	M	S	D,L,M,O	Fair		400	3-4	Sod capped w/ fines	M = 3000 ft^2 L = 400 ft	13 jetties = 105 c.y.	
14	Photo 11 1-R - 12R	M	S E= 200ft	D M,O	Fair	1625		4-20	Fine to coarse Alluvium	16,000 ft^2=M	10 jetties = 80 c.y.	
	12R -15NB	H	S	G;D=1500ft R=400 ft O.	Ex.		1400	4-15	Alluvium talluvial dikes	M=22,400 ft^2	50 jetties = 400 c.y.	450 c.y.RR
15	10-3A, EB-12EB	M	S	A,O,L,M,O	Fair	3250		3-4	Sand & fine gravel	50% reach 26000 ft^2=M 3300 ft = L	D= 1800 ft 60 jetties = 480 c.y.	
	Photo 9 1EB - 33MW	M	S E= 400ft	A,D,L,M,O	Good	5800		4	Fine Alluvium	M for 50% reach 30,000 ft^2=M 6000 ft = L	D= 2500 ft 83 jetties = 660 c.y.	
16	Photo 7 7-5EB to 18-0	M	S E= 400ft	A,D,L,M,O	Good	3200		3-4	Sand & fine gravel	50% reach, 26,000 ft^2=M 3300 ft = L	D=1750 ft 60 jetties = 480 c.y.	

Table C-1(cont.). SUMMARY OF RECOMMENDED BANK PROTECTION AND CHANNEL STABILIZATION MEASURES FOR PRICKLY PEAR CREEK.

Channel Reach	Site No.	Priority	Problem	Recommended Treatment	Access	Reach Length Ft.	Bank Length Ft.	Bank Height Ft.	Bank Material	Bank Area Requiring Veg.	Vol. of Rock for Gabions of Flow Deflections	Vol. of Rock for Rip-Rap
16 (contd.)	Photo 6 2EB-42EB	M	S E= 900ft	A,D,L,M,O	Good	6750		3-4	Sand & fine gravel	50% reach $40,000 ft^2$ = M 6000 ft = L	D=3000 ft 100 jetties = 800 c.y.	
17	Photo 5 1EB-58MW	M	S E= 900ft	A,D,L,M,O	Good	8000		3-4	Sand & fine gravel	50% reach $64,000 ft^2$ =M 6000 ft = L	D=4000 ft 133 jetties = 1100 c.y.	
	Photo 4 5EB-29EB	M	S E= 500ft	A,D,L,M,O	Good	[illegible]30		3-5	Rip rap to fine alluvium	50% reach $40000 ft^2$ = M 6000 ft = L	D=2000 ft 60 jetties = 480 c.y.	
18	Photo 3 2EB-15EB	M	S E= 400ft	A,D,L,M,O	Good	[illegible]		3-5	fine alluvium	50% reach $40,000 ft^2$ = M 6000 ft = L	D=4000 ft 130 jetties = 1040 c.y.	
	Photo 2 1EB-15MW	M	S E= 700ft	A,D,L,M,O	Good	3375		3-5	Fine Alluvium	50% reach $23,000 ft^2$ = M 4000 ft = L	D=2500 ft 80 jetties = 640 c.y.	

Table C-2. Designations of Channel Reaches on Prickly Pear Creek

The sites listed below are plotted on aerial photos on file at the Lewis and Clark County Conservation District office. Site 39-3, for example, is the third site plotted on photo 39.

Channel Reach	Sites included		
1	39-3	through	39-9
2	38-31		38-6.1
3	07-3		36-15
4	35-4		34-17
5	34-19		32-13
6	31-4		28-1
7	27-6		27-25
8	26-10		25-17
9	25-17		23-14
10	22-2		19-2.3
11	18-1		17-11
12	16-6		15-5
13	14-10		12-11
14	11-1		11-16
15	10-3		9-33
16	7-5		6-42
17	5-1		4-29
18	3-2		2-15

Table C-3.

Sites Proposed for Development
of Streamside Parks and Fishing Access

Site	Description
19-2.2	Excellent access from highway; now receives heavy recreational use but is not maintained. Located on Prickly Pear Creek just upstream of McClellan Creek. Has parking near stream.
19-2.3	Same as above; farther upstream.
22-2 to -3	Dense brush prevents access to stream at most points along this reach, which has good aquatic habitat. Paths could be cleared for fishing access, if landowner approves. Located near Montana City.
27-8	Channelized, but has excellent aquatic habitat, with many large boulders, deep pools, and riffles. The area east of the stream is waste land, with dredge tailings only partly vegetated. Could be developed into a roadside park or fishing access.
30-1-A to 30-6.1EB	Site of the old railroad roundhouse in Clancy. Here, over 1/2 mile of the Prickly Pear channel is completely riprapped and straightened along the edge of I-15. Carefully placed stream meanders could be designed within this almost completely flat 300 x 2,000 foot area. Trees and grasses could be planted to enhance aesthetics. This site is presently owned by Burlington Northern.

Fisheries Enhancement Demonstration Projects.

Many areas within channel reaches 6 through 10 are well suited for trout habitat improvement (see table III-1, p. 43). Enhancement of bank vegetation, creation of security and hiding areas along the banks and mid-channel, and the enhancement of pool-riffle contrast are improvements which would increase the trout productivity of these reaches. Alternatives A, B, and C include the use of random boulder clusters and flow deflection to improve habitat diversity and cover within sections of channel reaches 6 to 10. In addition to these measures, several additional types of habitat improvements could be made in these areas:

the use of log check dams to create pool-riffle contrast;

the use of bank-logs to create cover adjacent to banks;

creation of undercut banks, using logs and crushed rock to build special bank cover habitat structures.

Because of the relatively high bed-material load of the stream now, performance and longevity of these improvements may be limited. For example, a log check dam creates a small pool upstream at moderate and low flows. It also traps coarse sediment and gradually fills, reducing the pool habitat.

Careful placement of instream habitat improvements can improve their longevity and effectiveness. On Prickly Pear Creek where the stream gradient is relatively high (0.01 to 0.001), it may be possible to design and construct self-maintaining structures which do not accumulate sediment. The 2,400-foot section of channel in Channel Reach 10, upstream from the McClellan Creek confluence, is excellent for a demonstration project to test the effectiveness of instream habitat structures on Prickly Pear Creek.

This section of stream is relatively straight, lacks bank cover, and has poorly developed pools. In addition to the placement of random boulder clusters, the habitat improvements listed in table C-4 could be made. Costs and quantities listed in the table are based on preliminary analysis of the channel hydrology and geomorphology.

A detailed channel survey and hydraulic analysis along with consideration of site-specific aquatic habitat will allow preparation of final design specifications.for the project. The cost of constructing these improvements could be reduced by as much as 50 per cent if volunteer labor (both hand and heavy equipment) is available. A large backhoe and dump truck will be needed for much of the work.

Table C-4. Instream Habitat Improvements for Fisheries Demonstration Project in Channel Reach 10.

Structure	Quantity	Cost
Log check dam	4	$2,000
Bank cover logs	10	5,000
Bank cover habitat structure (log overhangs)	2	3,500
		10,500
Engineering and design		2,600
	Project Total	**$13,100**

The long-term effectiveness of these habitat improvements should be evaluated in two ways. First, fish population estimates should be made before and after installation. Second, detailed channel surveys should be made immediately after construction. Twice a year, these areas should be resurveyed to document the accumulation or scour of sediment and the condition of the structure.

Many of the trout habitat improvement projects would be well-suited for volunteer work, supervised or monitored by stream scientists and engineers. The Conservation Districts could work with local sportsmen's groups, youth groups, and landowners on several of the projects.

A funding proposal for a demonstration project could be submitted to a state agency such as the Montana Department of Fish, Wildlife, and Parks or the Montana Department of Natural Resources and Conservation, under one or several of the grant programs described in Chapter 5. Aquatic enhancement work could be "piggy backed" onto channel and bank stabilization work recommended for Channel Reaches 6 through 10 (McClellan Creek to Clancy).

APPENDIX D.

PRELIMINARY COST ESTIMATES FOR CHANNEL REHABILITATION

TABLE D-1

Cost Estimates for Channel Rehabilitation by Reach and Priority

Treatment	Units	Unit Cost
A. Reshape bank	ea.	$500
B. Riprap bank base	cu. yd.	20
C. Riprap channel bank	cu. yd.	15
D. Rock jetties	cu. yd.	25
E. Gabions	cy. yd.	40
F. Boulders	ea.	100
G. Alter channel	cy. yd.	6
H. Access bridge	ea.	5000
I. Slope drainage	lin. ft.	5
J. Retaining wall	cu. yd.	20
K. Clear debris	ea.	500
L. Sprigg--live stake	sq. ft.	0.75
M. Revegetate	sq. ft.	0.20
N. Wattle and plant	lin. ft.	1.00
O. Fence	lin.ft.	1.00
P. Log jetties	ea.	800
Q. Habitat structures	ea.	1750

Reach	Priority	Treatment	Quantity	Amount
1	M	A	1	$500
		D	50	1250
		K	1	500
		L	3500	2625
		M	2000	400
				5275
2	M	A	1	500
		B	50	1000
		D	10	250
		L	120	90
		M	800	160
				2000

Table D-1 (continued)
Cost Estimates for Stream Rehabilitation

Reach	Priority	Treatment	Quantity	Amount
2	H	A	1	$500
		B	80	1600
		L	120	90
		M	3000	600
				2790
3	M	A	1	500
		B	160	3200
		D	60	1500
		L	1240	930
		M	1740	348
		O	400	400
				6878
3	H	A	2	1000
		B	460	9200
		D	63	1575
		L	1290	967
		M	10900	2180
				14920
4	L	B	180	3600
		L	650	487
		M	650	130
				4217
4	M	A	0.5	250
		B	100	2000
		D	150	3750
		L	800	600
		M	7000	1400
				8000
4	H	A	0.5	250
		L	100	75
		M	300	300
				1025
5	L	L	3000	2250
		M	15000	3000
				5250
5	M	B	25	500
		D	44	1100
		L	1480	1110
		M	3200	640
				3350

Table D-1 (continued)
Cost Estimates for Stream Rehabilitation

Reach	Priority	Treatment	Quantity	Amount
5	H	A	2	$1000
		B	500	10000
		D	35	875
		L	1410	1058
		M	11100	2220
		N	1800	1800
				16953
Clancy Creek	H	M	66000	13200
		O	49632	49632
				62832
Warm Springs Creek	H	D	165	4125
		L	2500	1875
		M	26400	5280
		O	10560	10560
				21840
6	L	D	25	625
		L	870	652
		M	3300	660
				1937
6	M	A	1	500
		B	500	10000
		D	120	3000
		L	11720	8790
				23090
6	H	F	60	6000
7	L	F	8	800
		L	420	315
				1115
7	M	A	0.5	250
		D	18	450
		H	1	5000
		L	170	127
		M	2000	400
				6227
7	H	A	0.5	250
		B	230	4600
		L	270	203
				5053
8	L	L	1000	750

Table D-1 (continued)
Cost Estimates for Stream Rehabilitation

Reach	Priority	Treatment	Quantity	Amount
8	M	B	120	$2400
		D	45	1125
		L	900	675
		M	2250	450
				4650
8	H	F	40	4000
9	L	B	40	800
		D	20	500
		L	840	630
		M	1300	260
				2190
9	M	A	0.5	250
		B	220	4400
		L	870	652
				5302
9	H	A	10	5000
		B	820	16400
		F	70	7000
		J	140	2800
		I	200	1000
		L	1420	1065
		M	31900	6380
		N	5280	5280
				44925
10	L	M	3700	740
10	M	K	0.5	250
		M	2000	400
				650
10	H	A	1	500
		B	280	5600
		F	130	13000
		L	400	300
			27000	5400
				24800
11	M	A	2	1000
		D	500	12500
		L	7450	5588
		M	25700	5140
		O	11000	11000
				35227

Table D-1 (continued)
Cost Estimates for Stream Rehabilitation

Reach	Priority	Treatment	Quantity	Amount
12	H	J	2300	$46000
		L	2000	1500
		M	13000	2600
				50100
13	L	D	80	2000
		L	300	225
		M	6250	1250
				3475
13	M	A	2	1000
		B	170	3400
		D	609	15225
		L	3830	2872
		M	23850	4770
		O	16950	16950
				44217
13	H	B	450	9000
		L	400	300
		M	6000	1200
				10500
14	M	D	80	2000
		M	16000	3200
		O	9750	9750
				14950
14	H	A	2	1000
		B	450	9000
		G	1000	6000
		D	400	10000
		M	22400	4480
				30480
15	M	A	4	2000
		D	1140	28500
		L	9900	7425
		M	56000	11200
		O	8100	8100
				57225
16	M	A	4	2000
		D	1280	32000
		L	9300	6975
		M	66000	13200
		O	9000	9000
				63175

Table D-1 (continued)
Cost Estimates for Stream Rehabilitation

Reach	Priority	Treatment	Quantity	Amount
17	M	A	4	$2000
		D	1580	39500
		L	12000	9000
		M	80000	16000
		O	8700	8700
				75200
18	M	A	4	2000
		D	1680	42000
		L	10000	7500
		M	63000	12600
		O	9750	9750
				73850

Total Cost	
High priority	$296,220
Medium priority	$429,268
Low priority	$19,675
Total	$745,163
Plus 25% engineering and contingencies	$931,453

TABLE D-2

Costs for Protection of Structures Threatened by Erosion

Channel Reach	Treat-ment	Quan-tity	Amount	Plus Engineering, Contingencies (+25%)
1	------ No Sites ------			
2	B	50	$1000	$1250
3	A	1	500	
	B	280	5600	
	D	10	250	
	L	350	262	
	M	4200	840	
			7452	9320
4	A	1	500	
	B	160	3200	
	D	150	3750	
	L	900	675	
	M	8400	1680	
			9805	12260
5	A	5	250	
	B	70	1400	
	L	100	75	
	M	900	180	
			1905	2380
6	A	2	1000	
	B	500	10000	
	D	50	1250	
	L	5700	4275	
	M	7300	1460	
			17985	22500
7	A	0.5	250	
	B	150	3000	
	L	150	113	
			3363	4200
8	A	1	500	
	B	120	2400	
	D	45	1125	
	L	700	525	
	M	2310	462	
			5012	6300

Table D-2 (continued)
Costs for Protection of Structures Threatened by Erosion

Channel Reach	Treat- ment	Quan- tity	Amount	Plus Engineering, Contingencies (+25%)
9	B	40	$800	
	L	100	75	
			875	$1100
10	A	0.5	250	
	B	280	5600	
	L	400	300	
	M	6000	1200	
			7350	9200
11	------ No Sites ------			
12	------ No Sites ------			
13	A	1	500	
	B	450	9450	
	L	400	300	
	M	6000	1200	
			11450	14310
14	A	1	500	
	B	150	3000	
	L	60	1500	
	M	6000	1200	
			5800	7250
15	A	1	500	
	D	200	5000	
	L	600	450	
	M	4000	800	
			6750	8440
16	A	2	1000	
	D	400	10000	
	L	1500	1125	
	M	13000	2600	
			14725	18400
17	A	2	1000	
	D	400	10000	
	L	1600	1200	
	M	14000	2800	
			15000	18750

Table D-2 (continued)
Costs for Protection of Structures Threatened by Erosion

Channel Reach	Treat-ment	Quan-tity	Amount	Plus Engineering, Contingencies (+25%)
18	A	2	$1000	
	D	300	7500	
	L	1200	900	
	M	11000	2200	
			11600	$14500

****

Cost Summary
for Protection of Structures Threatened by Erosion

Channel Reach	Cost	Sub-Totals
1	$ 0	
2	1250	
3	9320	
4	12260	
5	2380	
		$25210
6	22500	
7	4200	
8	6300	
9	1100	
10	9200	
		43300
11	0	
12	0	
13	14310	
14	7250	
		21560
15	8440	
16	18400	
17	18750	
18	14500	
		60090
	Total Cost	$150,160

TABLE D-3

Summary of Costs for Streambank Fencing below East Helena

Channel Reach	Quantity (lineal feet)	Cost (+25%)
13	16,950	$21,200
14	9,750	12,200
15	8,100	10,100
16	9,000	11,300
17	8,700	10,900
18	9,750	12,200
	Total	$77,900

APPENDIX E.

REWATERING PRICKLY PEAR CREEK BY FLOW DIVERSION AND OFF-STREAM STORAGE OF SPRING RUNOFF

Dewatering of Prickly Pear Creek north of East Helena severely damages aquatic habitat and floodplain vegetation.

The following analysis shows that in an average year spring runoff is sufficient for storage and subsequent release to meet instream flow needs, but that this is not now feasible, because of legal, financial, and technical constraints.

Water Availability.

Diehl's Diversion and Storage Proposal.

The mean annual runoff of the basin and the existing demands placed on the water determine the availability of water for storage in the Prickly Pear drainage. This was studied in 1974, when the Montana Department of Natural Resources and Conservation (DNRC) evaluated a proposal by Diehl Development Corporation to divert and store water (Montana DNRC 1974).

Diehl Development Corporation applied in 1973 to DNRC for a beneficial water-use permit to remove and store 20 cfs from September 16 to April 14 of each year. The proposed diversion point was slightly downstream from the U.S. Geological Survey stream gauge near Clancy. The corporation planned to pump water through a pipeline to two holding reservoirs, of 21,000 and 250 acre-feet capacity, respectively. Details of the Clark Gulch site are summarized in table E-1. In addition to the proposed diversion of 20 cfs (Alternative 1), DNRC considered two other diversion schemes, of 10 and 5 cfs (Alternatives 2 and 3).

The Diehl application was for about 8,500 acre-feet. DNRC examined mean-monthly and low-flow records, and estimated that only about 4,000 acre-feet would be available after existing water rights had been satisfied. (Municipal and industrial water rights in 1974 were 14.3 cfs; in absence of measurements of irrigation withdrawals, agricultural water usage was estimated at 5 cfs for the early and late irrigation seasons). Under Alternative 1, April is the only month in which the full 20 cfs diversion could be removed. If 20 cfs were pumped at any other time,

Table E 1. Cost summary of Diehl Development Corporation's water-development proposal for Clark Gulch.

	ALTERNATIVE 1 20 c.f.s.	ALTERNATIVE 2 10 c.f.s.	ALTERNATIVE 3 5 c.f.s.
Construction			
Clark Gulch Dam	$5,400,000	$2,700,000	$1,900,000
Pumping System	470,000	450,000	430,000
Total Construction	$5,870,000	$3,150,000	$2,330,000
Annual			
Construction (30 years at 8%)	$ 521,414	$ 279,805	$ 206,967
Pumping (Power)	36,328	29,542	15,651
O & M (1% of Construction)	58,700	31,500	23,300
Total Annual	$ 616,442	$ 340,847	$ 245,918
Average Annual Water Available (A.F.)	4,006	3,340	1,610
Average Annual Acres Irrigated	1,335	1,113	537
Average Annual Cost Per Acre Foot	$ 153.88	$ 102.05	$ 152.74

Source: DNRC 1974, table 16.

TABLE E-2 Availability of Water for Diversion and Storage in the Upper Prickly Pear Drainage

Average Month	Mean Monthly Discharge near Clancy	[1] Amount of flow assumed diverted for prior rights	[2] Instream flow assumed needed	Monthly flow deficit or surplus	[3] Flow which could potentially be diverted and stored for in-stream release	[6] Possible flow release for in-stream purposes	[7] Potential actual streamflow below diversion point
Oct.	31.6 cfs (1880 AC-ft)	19.3 cfs (1150 AC-ft)	17 cfs	-5 cfs (300AC-ft)	0	300 AC-ft	17 cfs (1011 AC-ft)
Nov.	29.9 (1779)	14.3 (850)		-2 (120)	0	120	17 (1011)
Dec.	24.1 (1434)	14.3 (850)		-7 (420)	0	420	17 (1011)
Jan.	21.1 (1255)	14.3 (850)		-10 (600)	0	600	17 (1011)
Feb.	24.0 (1428)	14.3 (850)		-7 (420)	0	420	17 (1011)
Mar.	31.9 (1898)	19.3 (1150)		-4 (240)	0	240	17 (1011)
Apr.	52.6 (3130)	19.3 (1150)'		+16.3 (970)	16.3 cfs (970 AC-ft)	not necessary flow is high enough	17 (1011)
May	110 (6545)	19.3 (1150)		+73.7 (4385)	[5] 36 (2193)	" " "	54 (3204)
Jun.	140 (8330)	19.3 (1150)		+103.7 (6170)	[5] 52 (3085)	" " "	69 (4096)
Jul.	55.1 (3297)	55.1 (3279)		[4] -17 (1011)	0	1011	17 (1011)
Aug.	29.0 (1725)	29.0 (1725)		[4] -17 (1011)	0	1011	17 (1011)
Sep.	29.0 (1725)	29.0 (1725)		[4] -17 (1011)	0	1011	17 (1011)
	34,408 AC-ft	15,879 AC-ft	12,300 AC-ft	Total of surplus months = 11525 AC-ft	6248 AC-ft	5133 AC-ft	17410 AC-ft

[1] 14.3 cfs non ag. water rights + 5 cfs in Mar, Apr, May, Jun, & Oct.; all flow assumed used in Jul, Aug, + Sept.

[2] instream flow estimate is for maintaining trout populations in fall, winter & summer from diversion point down to E. Helena

[3] (mean monthly flow) -(prior water rights + instreamflow)

[4] All streamflow assumed used for Ag & Non Ag. water rights

[5] of surplus flow, 50% is assumed diverted, leaving 50% for simulated peak spring flow

[6] the water stored in spring (6242 AC-ft) could be released to make up the required 17 cfs later

[7] storage and redistribution of the 6248 AC-ft plus not diverting all spring runoff could result in these mean monthly flows

prior rights would be infringed. In addition, under this alternative Prickly Pear Creek would be totally dewatered below the last downstream appropriator during all months of pumping except April.

The Montana Department of Fish, Wildlife, and Parks determined that all the alternatives considered would adversely affect the fisheries resource, with Alternatives 1 and 2 leading to the greatest impacts (Montana DNRC 1974).

Clearly, the Diehl proposal was designed to avoid the problem of competing with a heavy but unknown summer irrigation demand. A synthesis or adjudication of existing water rights is needed to establish the amount of water available for storage for instream flow purposes. Even if the basin is over-appropriated, water may still be available.

Estimate of Water Potentially Available.

To estimate the amount of water potentially available for diversion, storage, and subsequent instream flow release, a continuous instream flow requirement of 17 cfs was assumed for the channel reach from Montana City to Clancy. This value is the minimum flow required to sustain a fishery, as determined by the Montana DFWP in the early 1970's (Montana DNRC 1974). In addition, only 50 per cent of the surplus water (water left after satisfying existing rights) in May and June was assumed diverted for storage. This allowed for a simulated spring peak flow approaching bankfull stage.

A municipal and industrial water rights requirement of 14.3 cfs was assumed, following the recommendation of DNRC (Montana DNRC 1974). Agricultural water rights of 5 cfs were assumed for the early and late irrigation seasons (March through June, and October, respectively). It was further assumed that all available streamflow was used by agriculture from July through September, so that the stream was totally dewatered below East Helena during this period.

Average annual and mean monthly flows for the U.S. Geological Survey gauging station near Clancy were obtained from published sources.

The surplus water available was then calculated using the following relationship:

$$\left[C - (A + B)\right]k = D$$

where C = mean monthly flow,
A = instream flow requirement of 17 cfs,
B = 14.3 cfs year round, plus 5 cfs in October and March through June,

k = per cent of surplus flow diverted for storage, assumed as 100 per cent during April, and 50 per cent in May and June, and

D = surplus water available for storage after satisfaction of existing water rights.

This equation was used to prepare table E-2, which shows the possiblities for diversion, storage, and later release of water to achieve a minimum instream flow of 17 cfs throughout the year.

As can be seen, the mean annual runoff from the Prickly Pear Creek drainage above the gauging station (an area of about 192 square miles) is 34,408 acre-feet. Of this, it is assumed that 10,200 acre-feet is required to satisfy year-round 14.3 cfs non-agricultural water rights, and 5,679 acre-feet to satisfy agricultural use. This leaves 18,529 acre-feet for instream uses. A continuous flow of 17 cfs for 12 months amounts to 12,300 acre-feet, leaving about 6,225 acre-feet for additional release in May and June.

Note that of the 18,529 acre-feet potentially available, only 17,410 is used. Similarly, of the 6,225 acre-feet available for spring storage, only 5,133 is required to bring deficit months up to the minimum 17 cfs.

Under the scenario of table E-2 about 11,525 acre-feet of water could be diverted and stored in the average spring. Allowing for a two-month period of elevated streamflow in May and June, this amount is reduced to 6,248 acre-feet. The latter compares favorable with the amount (about 5,133 acre-feet) actually required to bring flow deficit months up to 17 cfs.

As discussed in Chapters II and III and Appendix F, the dewatered reach below East Helena has a higher instream flow requirement (about 20 to 40 cfs) than the section of channel between East Helena and the gauging station (17 cfs) for which the calculations above were made. In order to provide 20 to 40 cfs of flow to the downstream reach during the peak irrigation season, an additional 600 to 3,400 acre-feet of the spring surplus would have to be stored.

Conclusions.

Based on the estimates and simplified assumptions in this analysis, we conclude that sufficient spring runoff is available in the average year for storage and release for instream flow needs. However, several significant con straints limit the feasibility of of this procedure.

First, there are legal and political problems in obtaining an instream flow reservation in a drainage which

is over-appropriated. Also, the water rights adjudication process needs to be completed before making a reasonable estimate of water demand and use versus water rights.

Another constraint is cost. Off-stream storage is very expensive (more than five million dollars), and suitable sites are limited (see Chapter III).

A third constraint is that the analysis presented here relies on mean annual and mean monthly flow information, and does not reflect the annual variation in wet and dry years.

In all likelihood, an offsite storage capacity of perhaps 15,000 to 20,000 acre-feet would be needed to smooth out this variation. This is several times greater than the 5,133 acre-feet required in an average year.

Finally, offstream storage for instream flow purposes alone is very unlikely. Other interests, such as agriculture, land developers, and municipalities, would require consideration. It would be difficult to satisfy all competing water users and be left with sufficient water for instream flow purposes.

Given these constraints, rewatering Prickly Pear Creek by flow diversion and offstream storage is not presently feasible.

APPENDIX F.

INSTREAM FLOW REQUIREMENTS FOR DEWATERED REACH

Numerous factors influence the amount of flow required to provide adequate habitat for aquatic life in Prickly Pear Creek. The amount of flow required at a particular site depends strongly upon the shape of the channel cross-section and on its hydrology. For example, between East Helena and Montana, where the channel is relatively narrow (about 30 ft) and deep, the Montana Department of Fish, Wildlife, and Parks determined 17 cfs to be the minimum flow for sustaining a viable trout fishery (Montana DNRC 1974). This flow provides sufficient depth for fish migration and produces enough cover and security areas to maintain a modest trout population. On the other hand, below East Helena in the dewatered section near Helena Sand and Gravel the channel is generally much wider (40 to 110 ft) and shallower, and requires a greater flow to maintain suitable habitat. Our calculations of this flow are presented below.

Assumptions.

For our analysis, fish migration was considered very important. A flow depth of 0.4 ft should be enough for fish migration. While it could be argued that a depth of 0.2 ft would be adequate for migration alone, it is likely that stream temperature would then rise, limiting aquatic populations. In addition, some percentage of the water would be lost to seepage and evapotranspiration. These losses could cumulatively reach 10 to 30 per cent of the flow released into the dewatered reach.

The flow required to give a water depth of about 0.4 to 0.6 ft in riffle sections of channel reach 14 (photo 11) was estimated using the slope/area method and appropriate channel hydraulic information. A stream profile and cross-sections of Channel Reach 14 were surveyed on October 3, 1983. The profile is shown in figure F-1. At the time of the survey, the water depth in pools was about 1 ft, while the depth over riffles was about 0.4 to 0.6 ft. The discharge was indirectly calculated as approximately 40 cfs.

The discharge calculations are summarized in the following section. The calculations indicate that an optimum release of 30 to 40 cfs is necessary to rewater Prickly Pear Creek and maintain aquatic habitat.

With the stream channel in its present (1983)

configuration, a flow of about 40 cfs is needed to obtain a minimum flow depth of approximately 0.4 to 0.6 ft along riffles in Channel Reach 14. If channel reconstruction and revegetation efforts are successful, it may be possible to maintain a stable channel with a smaller width (and width/depth ratio). In this case, about 30 cfs could give the same flow depth.

We assumed that it would be necessary to rewater the stream every year, from about July 15 to October 1--a period of 75 days. The total volume of water needed for a constant flow of 20 cfs for 75 days is 2,970 acre-feet, and for 40 cfs, 5,950 acre-feet.

The annual estimated cost of obtaining this water from the Helena Valley Canal is $30,000 to $60,000, assuming a unit price of $10.00 per acre-foot. The actual cost may vary considerably, depending upon future changes in U.S. Bureau of Reclamation policies, and upon the actual withdrawal schedule for the water (Schofield 1984).

Calculations of Discharge Needed to Provide Minimum Flow Depth of 0.5 Feet.

Method.

For critical sections of the dewatered reach, the flow volume was estimated using the slope/area method for gradually varied flow. Benson and Dalrymple (1967) give details of the method. Calculations were done using a program developed by Croley (1977) for the Ti-59 calculator. Constants, channel hydraulic information, and results are summarized in tables F-2, F-3, F-4, and F-5.

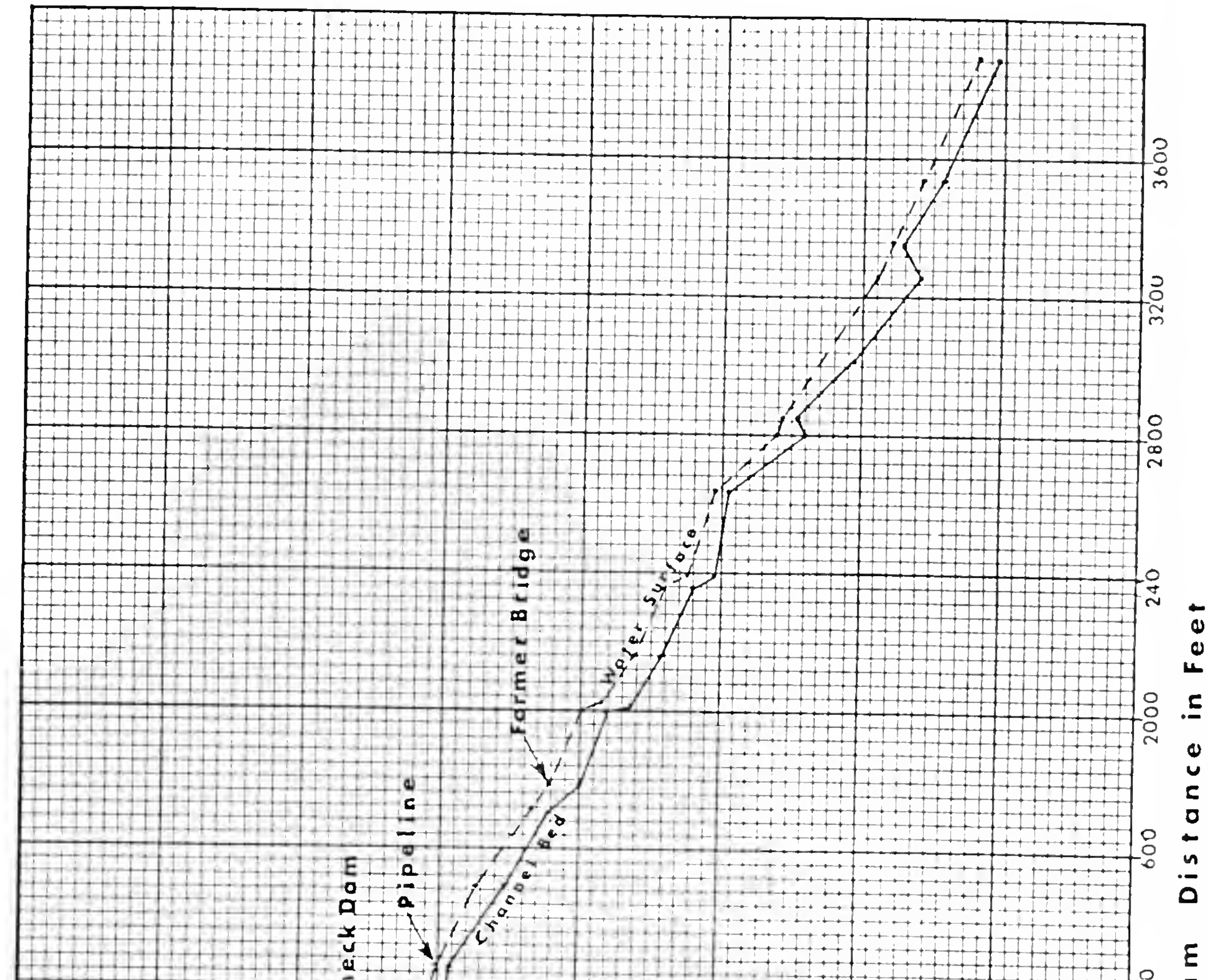


Figure F-1. Channel Profile of Gravel Pit Segment of Dewatered Reach

Table F-1. Hydrologic Information for Channel at Sites of Cross-sections IIX-2 and IIX-3.

	Cross-section IIX-2	Cross-section IIX-3
Width (w)	22 ft	39 ft
Area (a)	24 ft	25 ft
Avg. depth (d)	1.1 ft	0.6 ft
Wetted perimeter (wp)	25 ft	40 ft
Hydraulic radius (R=A/wp)	1.0 ft	0.6 ft
Bed elevation of thalweg	3,785.2 ft	3,784.8 ft
Water surface elevation	3,787.2 ft	3,785.4 ft
Manning n (calculated from Limerinos 1970)	0.048	0.059
Distance between cross-sections	442 ft	
Energy gradient	0.0041	

Bed-material size distribution at site: D84 = 77 mm, D50 =35 mm, D10 =9 mm.

Table F-2. Hydrologic Values for the Slope/area Calculations for Cross-sections IIX-2 and IIX-3.

Cross-section IIX-2	Cross-section IIX-3
α = 1	α = 1
n = 0.048	n = 0.059
A = 24 ft	A = 25 ft
R = 1 ft	R = 0.6 ft

K = 0.5, F = 1.8 ft, L = 442 ft.

Calculated discharge is 37 cfs, with a mean flow velocity of 1.5 ft/sec.

Table F-3. Hydrologic Information for Channel at Sites of Cross-sections IIX3 and IIX-4.

	Cross-section IIX-3	Cross-section IIX-4
Width (w)	39 ft	42 ft
Area (a)	25 ft	29 ft
Avg. depth (d)	0.6 ft	0.7 ft
Wetted perimeter (wp)	40 ft	43 ft
Hydraulic radius (R=A/wp)	0.6 ft	0.7 ft
Bed elevation of thalweg	3,784.8 ft	3,780.0 ft
Water surface elevation	3,785.4 ft	3,781.0 ft
Manning n (calculated from Limerinos 1970)	0.059	0.052
Distance between cross-sections	650 ft	
Energy gradient	0.0068	

Bed-material size distribution at site: D84 = 77 mm, D50 =35 mm, D10 =9 mm.

Table F-4. Hydrologic Values for the Slope/area Calculations for Cross-sections IIX-3 and IIX-4.

Cross-section IIX-3	Cross-section IIX-4
α = 1	α = 1
n = 0.059	n = 0.052
A = 25 ft	A = 29 ft
R = 0.6 ft	R = 0.7 ft

K = 0.5 ft, F = 4.4 ft, L = 660 ft.

Calculated discharge is 44 cfs, with a mean flow velocity of 1.8 ft/sec.

APPENDIX G.

STORAGE CAPACITY
OF HELENA SAND AND GRAVEL--BURNHAM GRAVEL PITS

Below East Helena about 1.5 to 2 miles, Helena Sand and Gravel has a mining and crushing operation. The largest of several abandoned mine pits is just south of Prickly Pear Creek. Based on a survey of the ponds and planimetry of aerial photo #2, the following information was obtained.

Total area of pond	555,420 square feet
Less area of unusable islands	-40,857
Usable area	514,563 square feet or 11.8 acres

The storage capacity was estimated by two methods:

Method 1. Assume that an embankment is constructed around the pond, so that the pond may be filled with water to an elevation of 3,793 feet, making it 17 feet deep with an area of 11.8 acres. The pond's volume is then 200 acre-feet. The pond could then store a continuous discharge of 100 cfs for 24 hours before spilling.

Method 2. Assume that no embankment is built. The pond could then fill to an elevation of 3786.9 feet, and would be 5.3 feet deep. Its storage capacity would be only 63 acre-feet.

These are relatively small storage capacities. By using other abandoned gravel pit ponds to the north of the present operation it may be possible to double or triple the available storage volume. This would still provide less than about 700 acre-feet of storage. Actual storage would be less because of seepage loss from the ponds. Assuming that 700 acre-feet could be stored, this would yield a continuous flow of 20 cfs for 17 days, a relatively small contribution.

Although the pond(s) may be well suited as sediment traps, their small capacities would only store roughly 23 per cent of the water required for instream purposes below Burnham's irrigation diversion.

APPENDIX H.

PRELIMINARY ESTIMATE OF COST FOR SPRINKLER IRRIGATION ON DON BURNHAM PROPERTY

Available Information:

Amount of land irrigated	400 acres
Amount of water required for average irrigation season	2 ac-ft/ac. (800 ac-ft total)
Typical yield of wells within 2 mile radius of property	100 to 1,250 gpm (ave.=500 gpm)
Type of sprinkler system desired	center-pivot, capacity of 6.5 gpm/ac or 11.5 ac-ft/day

Assumptions:

Installed capacity of well system	260 gpm
Well system	3 wells, 100 ft deep, 12 in. dia, steel cased, 870 gpm ea.
Cost/ft of well drilling and installation	$50-60/ft.
Cost of center-pivot sprinkler	$350-400/ac

Preliminary costs:

Detailed site study and ground-water evaluation, testing	$15,000-20,000
Cost for sprinkler system	$136,000-160,000
Cost for well development	$15,000-18,000
Total costs =	$166,000-198,000

APPENDIX I.

WATER-STORAGE CAPACITY OF ALLUVIAL AQUIFERS IN WOOD CHUTE GULCH

There are extensive terrace deposits of cobbles and gravel in the Wood Chute drainage and a portion of the Spring Creek drainage immediately below Wickes. The terraces probably formed by torrential stream deposition during the last glacial age. The modern streams flow in narrow valleys excavated into the terraces.

Potential Storage Capacity.

A rough estimate of the potential storage capacity for ground water was made for these terraces. The estimate was based on the following information and assumptions:

Potential storage capacity:

Area of terraces	1.26 square miles
Thickness of unsaturated aquifer	40 feet
Specific yield of aquifer	21-35%

Estimate of storage capacity:

Storage capacity = (area)(thickness)(specific yield)
= 6,720 acre-feet, assuming 21% specific yield
= 11,200 acre-feet, assuming 35% specific yield

Water Availability.

The volume of water potentially available for diversion, infiltration, and storage in the Wood Chute aquifer was estimated using three methods.

The first method is based on regional relationships between mean annual runoff and channel geometry (Parrett *et al.* 1983). This method results in a calculated mean annual runoff of 372 acre-feet, and a unit runoff of 93 acre-feet per square mile.

The mean annual runoff based on Wac alone is 6,504 acre-feet, and the unit runoff 1,641 acre-feet per square mile.

The second method is based on the average unit area runoff for the entire drainage above the U.S. Geological Survey gauging station near Clancy. The drainage are is 192 square miles, and the mean annual runoff about 35,000 acre-feet, giving a unit runoff of 183 acre-feet per square mile. Assuming that Wood Chute has this unit runoff, and a drainage area of four square miles, its calculated mean annual runoff is 732 acre-feet.

The third estimate is based on an approximate water balance for the Wood Chute drainage. Assuming a drainage area of four square miles, mean basin elevation of 6000 feet, and mean annual precipitation of twenty inches, then:

Total annual volume
of water = (area)(precipitation)
= 4,266 acre-feet.

In humid areas about 20 to 50 per cent of precipitation normally becomes runoff, so that the calculated mean annual runoff is probably between 853 and 2,133 acre-feet, and the unit runoff between 213 and 533 acre-feet.

The range of estimates for mean annual runoff of Wood Chute Creek above the proposed infiltration and storage site is given in the following table.

Table I-1. Calculated Estimates of Mean Annual Runoff for Wood Chute Creek

Method	Mean annual runoff (acre-feet)
Parrett *et al.* 1983	
Wac alone	6,564
Wac + Da	372
Unit runoff at Clancy Creek	732
Water Balance	850-2,100

Conclusions.

Based on annual runoff estimates of 400 to 2,000 acre-feet, water availability limits the amount of base flow augmentation possible through ground-water storage. Assuming that 50 per cent of this annual runoff is available for storage and infiltration, approximately 200 to 1,000 acre-feet could be stored. If released at a rate of five cubic feet per second, that would provide 20 to 100 days of increased flow.

While any amount of flow augmentation would be beneficial, the relatively small amount of flow available makes this approach marginal. Other tributary drainages in the Spring Creek watershed are smaller than four square miles lack suitable infiltration and storage sites.

06061500 PRICKLY PEAR CREEK NEAR CLANCY, MT

LOCATION.--Lat 46°31'05", long 111°56'45", in NE¼SW¼ sec.23, T.9 N., R.3 W., Jefferson County, Hydrologic Unit 10030101, on right bank 3.5 mi (5.6 km) downstream from Lump Gulch Creek, 4 mi (6 km) northeast of Clancy, and 7 mi (11 km) southeast of Helena.

DRAINAGE AREA.--192 mi^2 (497 km^2).

PERIOD OF RECORD.--July 1908 to September 1916, July 1921 to September 1933, October 1945 to October 1953, October 1954 to September 1969, October 1978 to September 1979. Monthly discharge only for some periods, published in WSP 1309.

REVISED RECORDS.--WSP 1086: 1946(m). WSP 1309: 1925, 1927, 1931(M), 1933, 1948(M). WSP 1729: Drainage area.

GAGE.--Water-stage recorder. Datum of gage is 4,067.1 ft (1,239.65 m) National Geodetic Vertical Datum of 1929. Prior to July 12, 1910, nonrecording gage at site 1.2 mi (1.9 m) upstream at different datum. July 12, 1910, to Sept. 30, 1916, and July 28, 1921, to Aug. 12, 1933, nonrecording gage at site 2.2 mi (3.5 km) upstream at different datum.

REMARKS.--Diversions for irrigation of about 700 acres (2.83 km) above station.

AVERAGE DISCHARGE.--44 years (water years, 1909-16, 1922-33, 1946-53, 1955-69, 1979), 48.3 ft^3/s (1.368 m^3/s) 34,990 acre-ft/yr (43.1 hm^3/yr).

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, about 900 ft^3/s (25.5 m^3/s) about June 9, 1927 (estimated on basis of hydrographic comparison); minimum, 0.5 ft^3/s (0.014 m^3/s) Jan. 26, 1958, gage height, 0.40 ft (0.122 m), backwater from ice.

EXTREMES OUTSIDE PERIOD OF RECORD.--Maximum discharge, 1,200 ft^3/s (34.0 m^3/s) June 19, 1975, gage height, 6.56 ft (2.000 m).

MONTHLY AND ANNUAL MEAN DISCHARGES 1909-16, 1922-33, 1946-53, 1955-69, 1979

MONTH	MAXIMUM (CFS)	MINIMUM (CFS)	MEAN (CFS)	STANDARD DEVIATION (CFS)	COEFFICIENT OF VARIATION	PERCENT OF ANNUAL RUNOFF
OCTOBER	70	13	32	14	.44	5.5
NOVEMBER	60	15	30	11	.37	5.2
DECEMBER	40	12	24	7.1	.29	4.2
JANUARY	30	9.9	21	5.3	.25	3.7
FEBRUARY	57	12	24	8.1	.34	4.1
MARCH	80	17	32	13	.42	5.5
APRIL	131	23	54	21	.40	9.3
MAY	194	38	110	37	.33	19
JUNE	450	27	138	85	.62	23.8
JULY	141	10	57	33	.58	9.8
AUGUST	76	6.3	29	15	.51	5.1
SEPTEMBER	71	9.3	29	15	.53	5.0
ANNUAL	85	19	48	16	.32	100

MAGNITUDE AND PROBABILITY OF ANNUAL LOW FLOW BASED ON PERIOD OF RECORD 1910-16, 1923-33, 1947-53, 1956-69

DISCHARGE, IN CFS, FOR INDICATED RECURRENCE INTERVAL, IN YEARS, AND NON-EXCEEDANCE PROBABILITY, IN PERCENT

PERIOD (CONSECUTIVE DAYS)	2 50%	5 20%	10 10%	20 5%	50 2%	100 1%
1	13	9.2	7.5	6.3	5.2	4.5
3	14	9.7	7.9	6.7	5.5	4.8
7	15	11	8.7	7.3	5.9	5.2
14	16	11	9.5	8.0	6.5	5.6
30	17	13	11	8.9	7.2	6.2
60	20	15	12	9.9	7.9	6.7
90	21	16	14	12	10	8.8
120	23	17	15	13	11	10
183	24	18	16	14	12	11

MAGNITUDE AND PROBABILITY OF INSTANTANEOUS PEAK FLOW BASED ON PERIOD OF RECORD 1911-75

DISCHARGE, IN CFS, FOR INDICATED RECURRENCE INTERVAL, IN YEARS, AND EXCEEDANCE PROBABILITY, IN PERCENT

1.25 80%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%
165	274	453	[illegible]	751	[illegible]	1040

WEIGHTED SKEW = 0.230

MAGNITUDE AND PROBABILITY OF ANNUAL HIGH FLOW BASED ON PERIOD OF RECORD 1909-16, 1922-33, 1946-53, 1955-69, 1979

DISCHARGE, IN CFS, FOR INDICATED RECURRENCE INTERVAL, IN YEARS, AND EXCEEDANCE PROBABILITY, IN PERCENT

PERIOD (CONSECUTIVE DAYS)	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%
1	233	360	446	556	638	[illegible]
3	211	321	396	492	564	[illegible]
7	[illegible]	283	350	438	516	[illegible]
15	169	243	311	387	445	[illegible]
30	[illegible]	213	275	324	368	412
60	122	174	[illegible]	242	[illegible]	[illegible]
90	105	142	166	192	[illegible]	[illegible]

DURATION TABLE OF DAILY MEAN FLOW FOR PERIOD OF RECORD 1909-16, 1922-33, 1946-53, 1955-69, 1979

DISCHARGE, IN CFS, WHICH WAS EQUALED OR EXCEEDED FOR INDICATED PERCENT OF TIME

1%	5%	10%	15%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	99%	99.5%	99.9%
262	150	105	78	64	46	37	31	27	23	20	17	14	11	9.6	7.9	5.6

(Source - Shields & White, 1981)

APPENDIX K.

STREAMWORKS PERSONNEL

The following Streamworks personnel and contractors prepared this report:

Robert L. Anderson, P.E., M.S., Water Resources Engineer

Ray H. Breuninger, Ph.D., Geologist, Streamworks Partner

Charles Dalby, M.S., Hydrologist, Geomorphologist, Streamworks Partner

Joe C. Elliott, Ph.D., Botanist and Ecological Consultant

Kenneth Knudson, M.S., Aquatic Biologist

Jim E. Richard, M.S., Community Planner, Wildlife Manager

Stewart Allen, Ph.D., Editor and Recreation Specialist